Lidar soundings of the middle atmosphere: Temperature, gravity waves and noctilucent clouds

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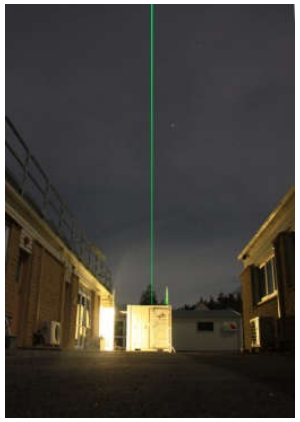
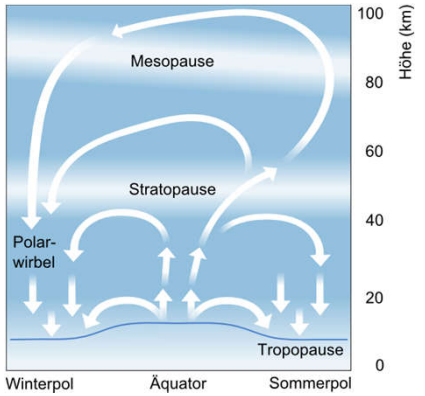
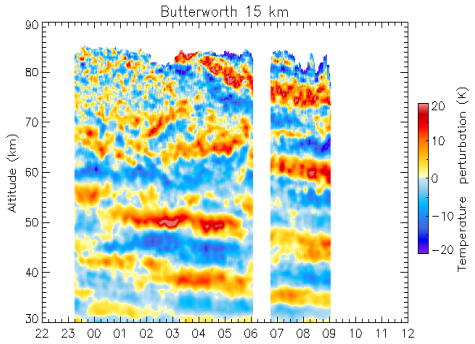
Outline

1. The middle atmosphere
   - Thermal state
   - Dynamics
2. Observations with lidar instruments
3. Gravity waves
   - Life cycle
   - Observation and analysis
4. Noctilucent clouds
   - History
   - Balloon campaign

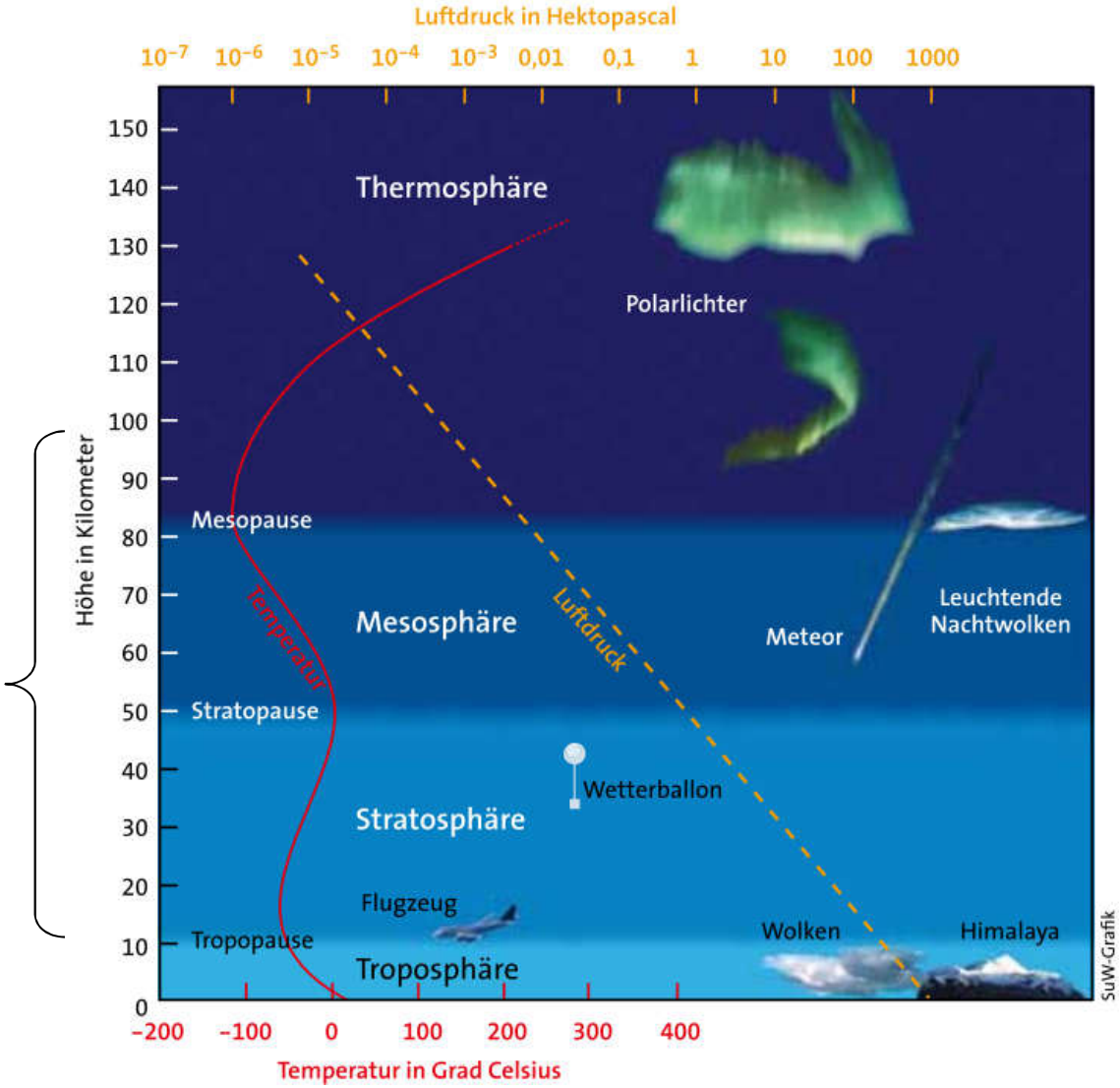




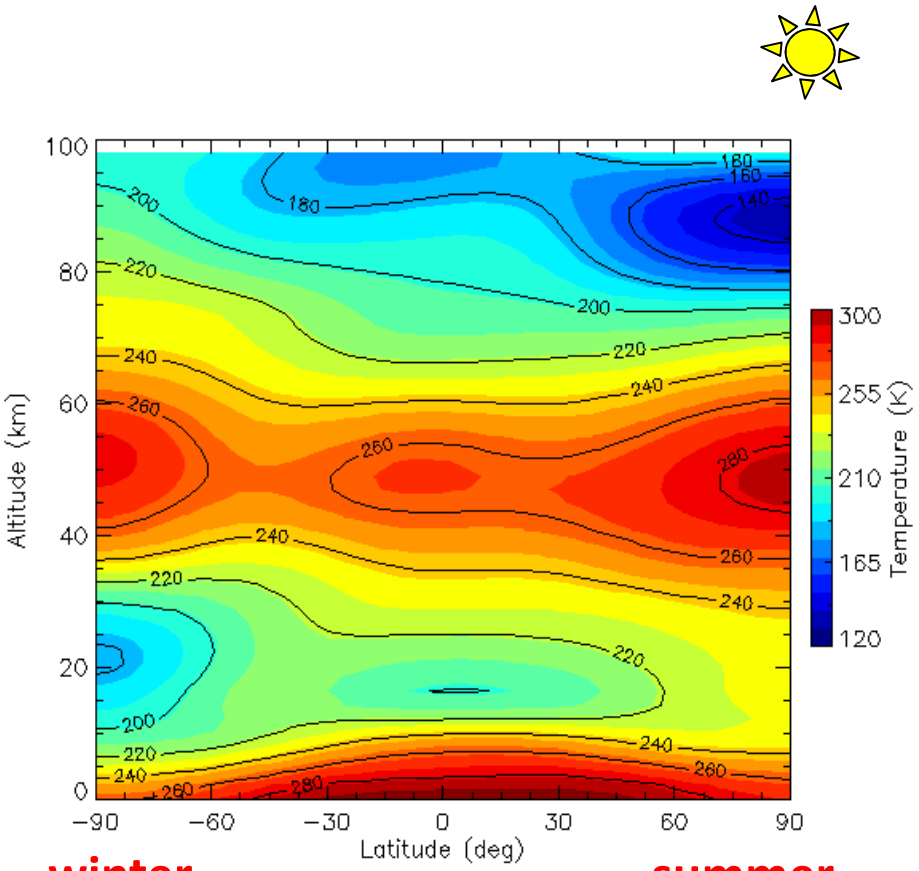


The middle atmosphere

- Mesosphere
  - ~50-90 km
  - Decreasing T
  - Meteors and noctilucent clouds
- Stratosphere
  - ~10-50 km
  - Increasing T due to ozone absorption



Thermal structure of the atmosphere

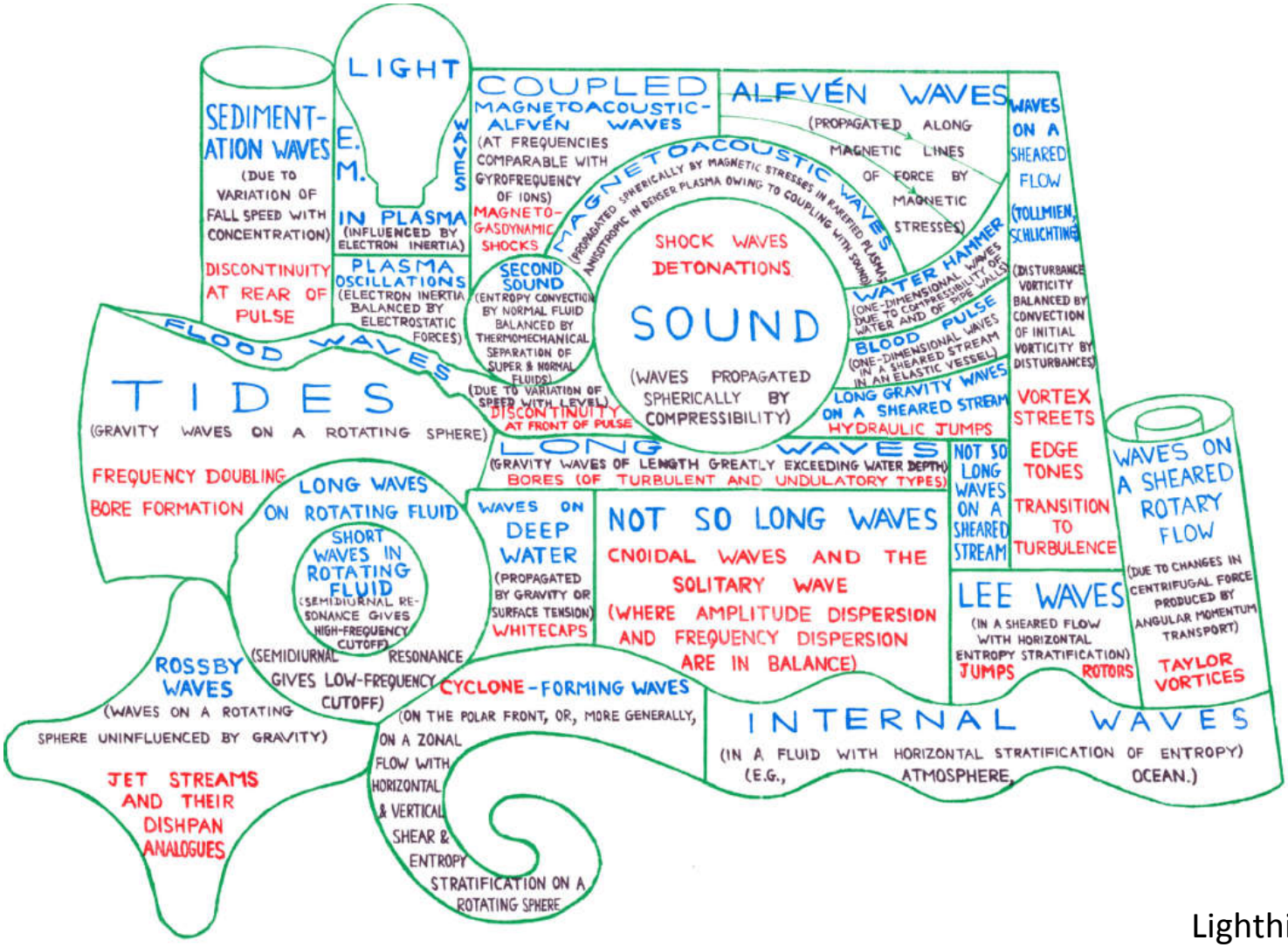


- Dependence on season/latitude
- The atmosphere is far from radiative equilibrium

→ dominated by dynamics

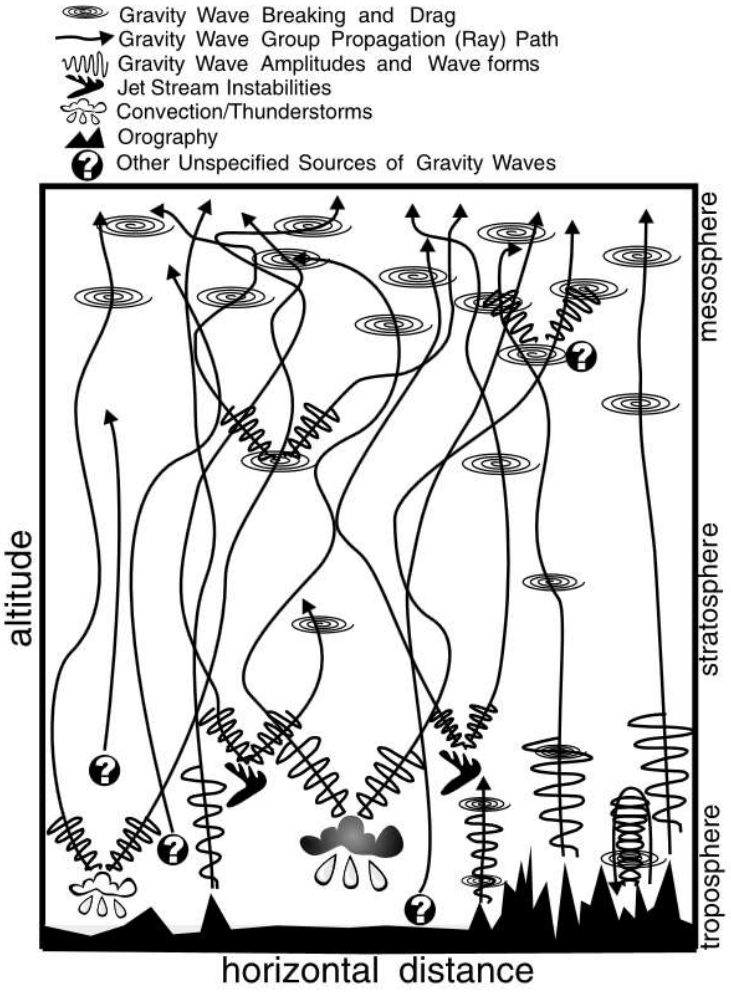
DLR

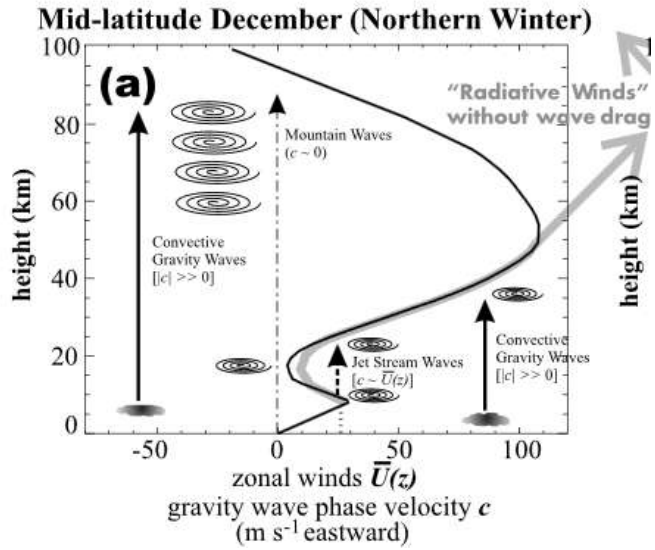
Waves in Fluids

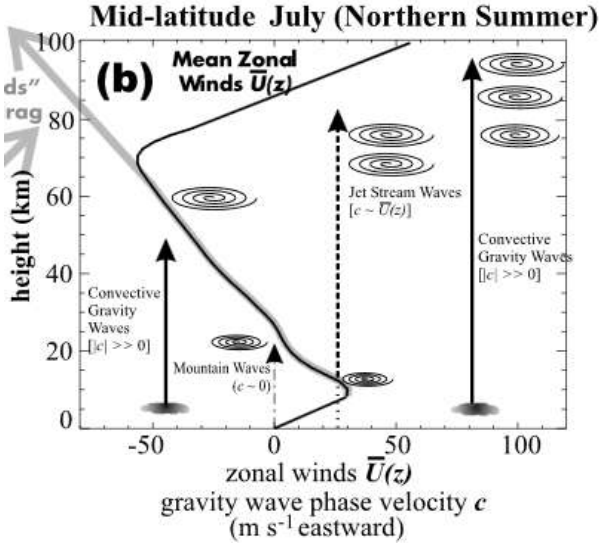


Lighthill, 1967

Gravity waves

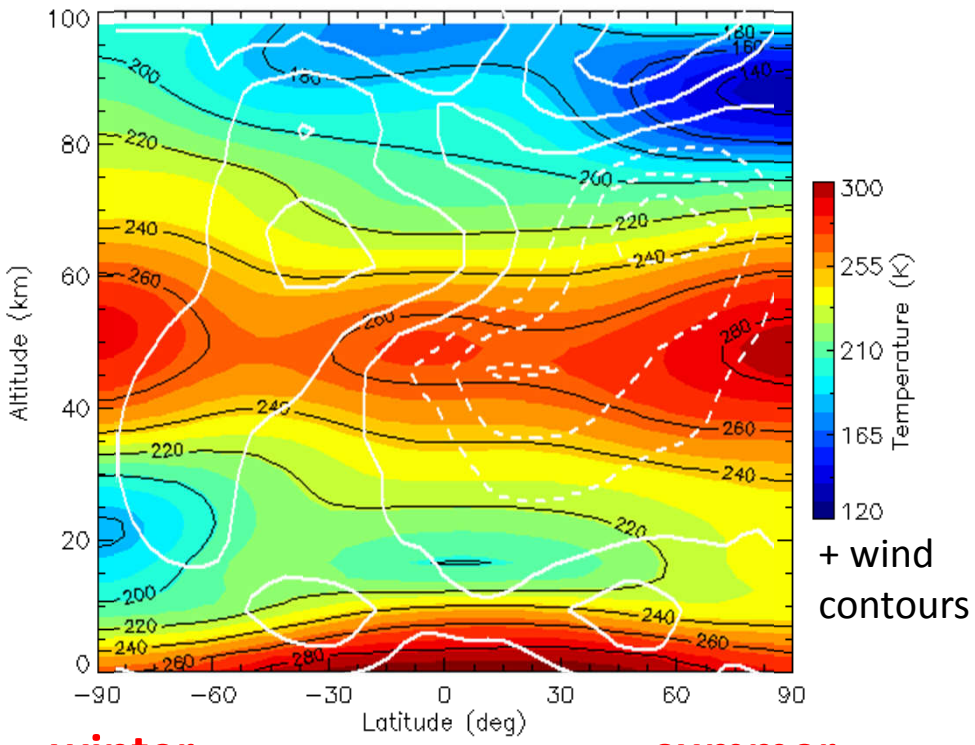


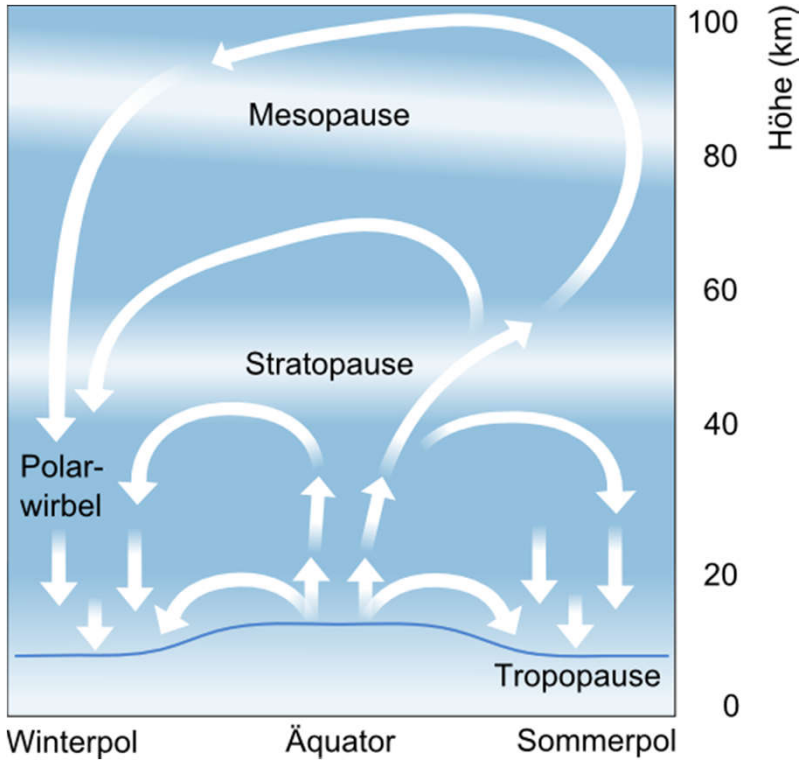


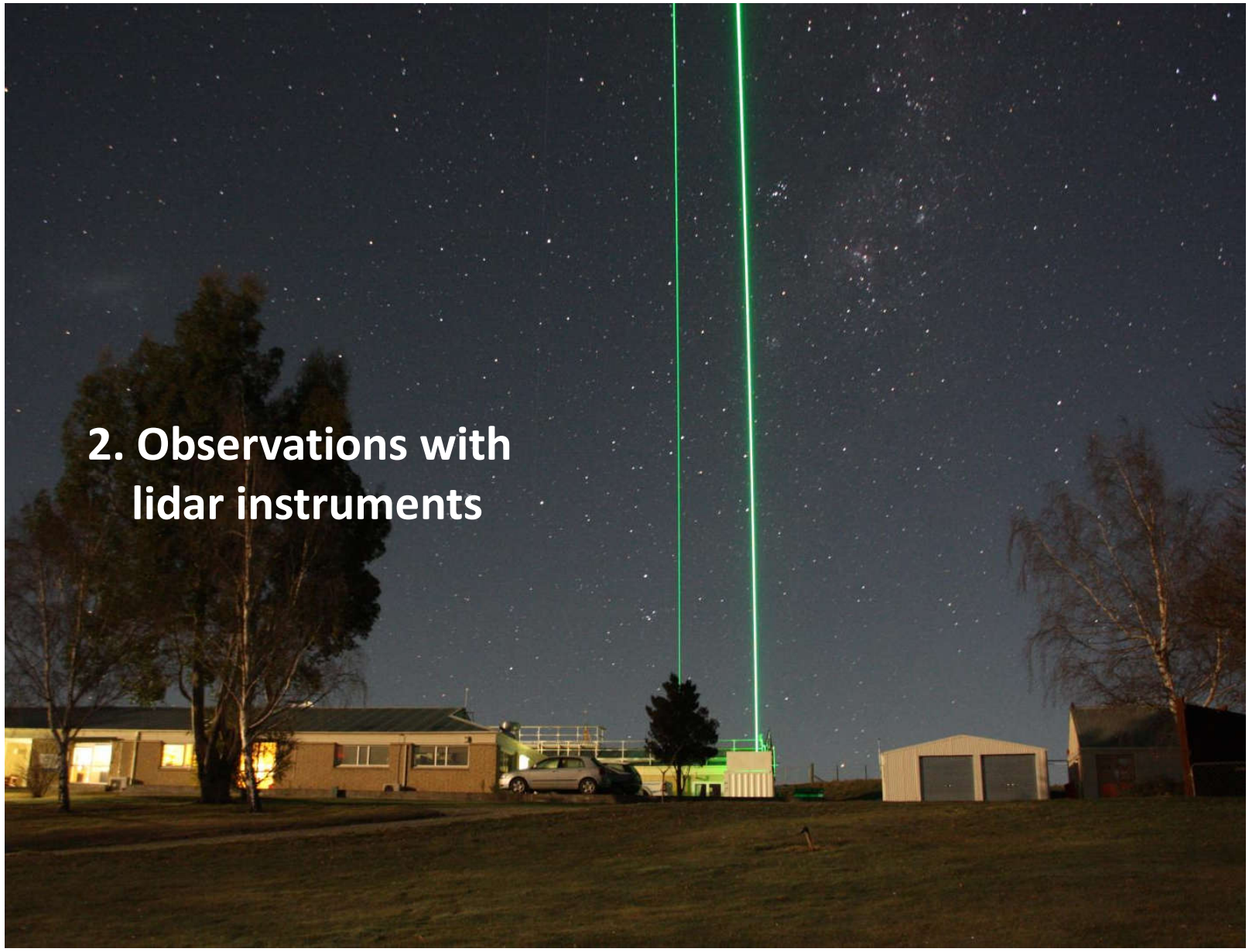


Kim et al., 2003

Thermal structure and circulation of the atmosphere

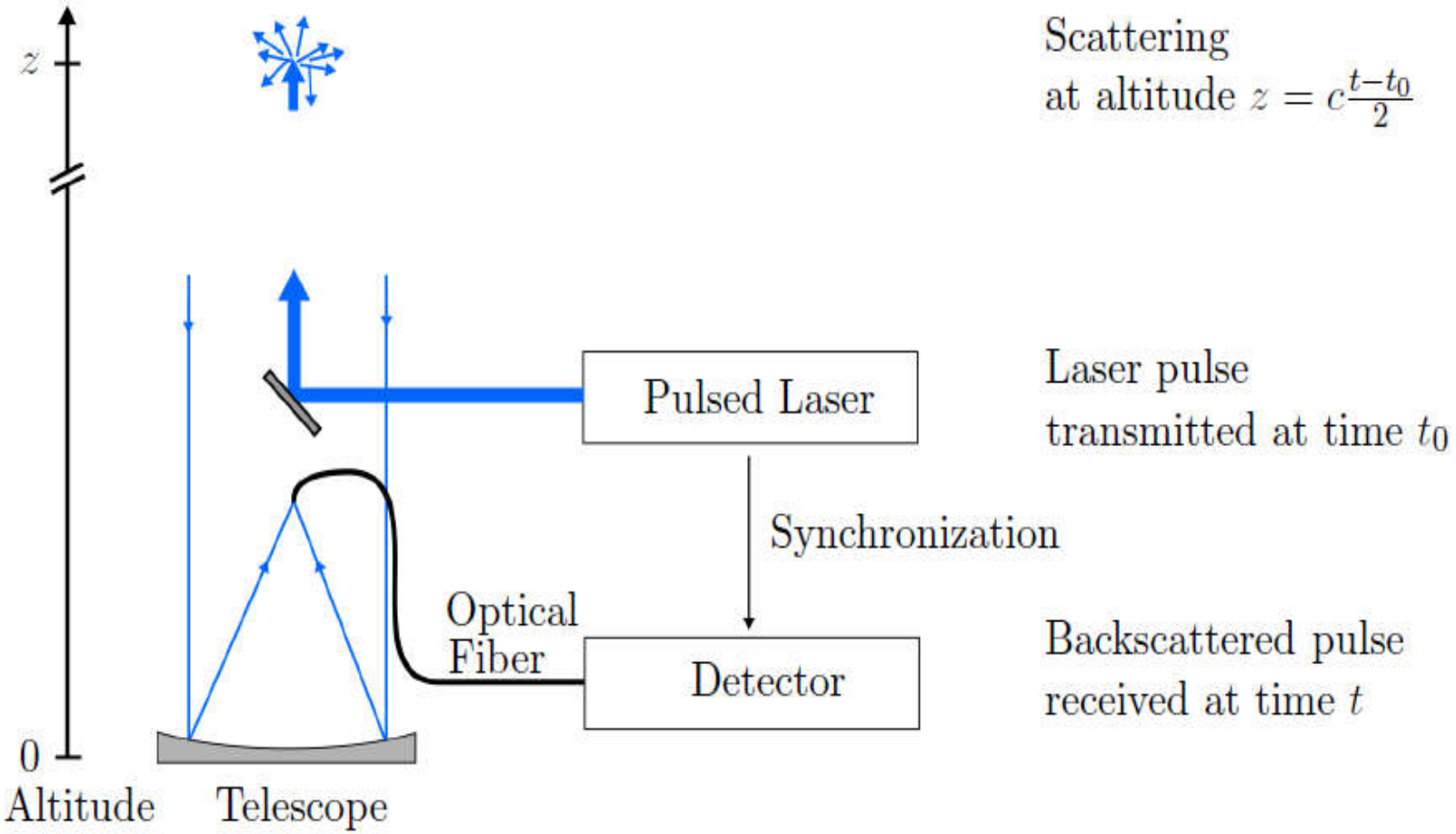






DLR

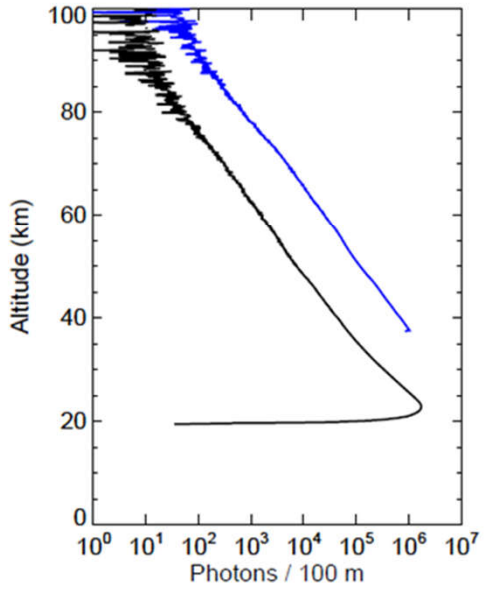
Sounding of the atmosphere with lidar



Lidar data

Measurement

Photon counts



Data Processing

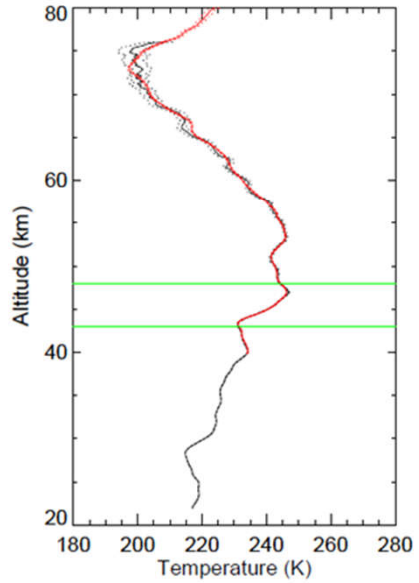
- Atmosphere is in hydrostatic equilibrium
- Ideal gas law
- Temperature T_0 at top of profile is „known“

Integration of photon count profiles from top z_0 to bottom z:

$$T(z) = \frac{S(z0)}{S(z)} T_0 + \frac{M}{k_B} \int_{z_0}^{z} \frac{S(z')}{S(z)} g(z')\, \mathrm{d}z$$

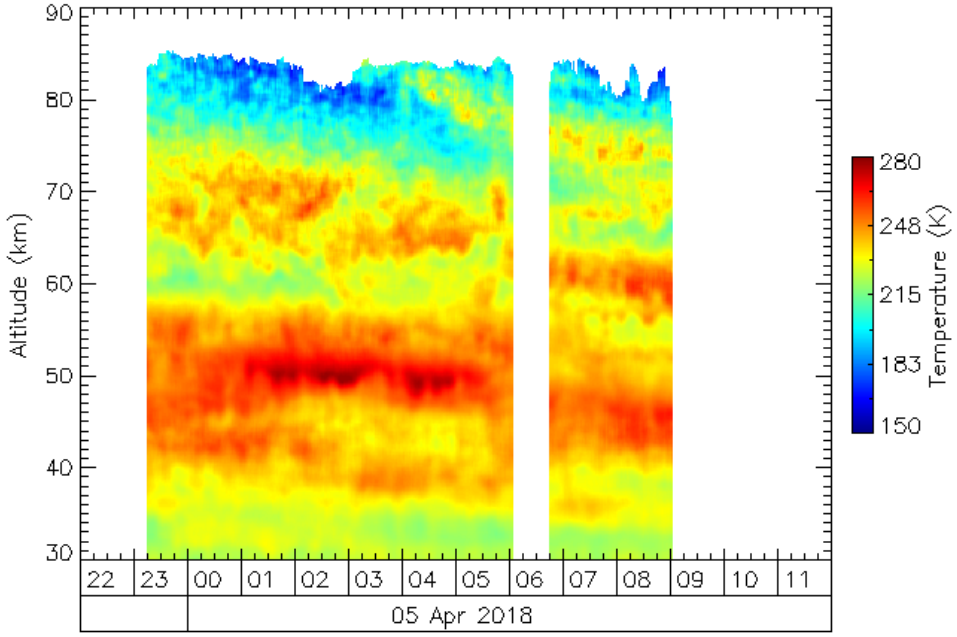
Data Product

Temperature profiles

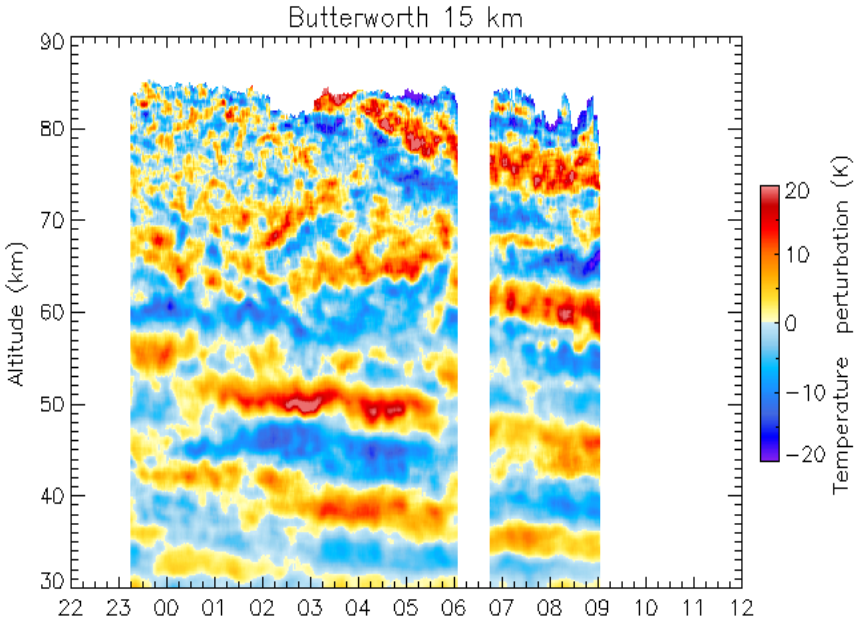


From temperatures to waves

- Temperature

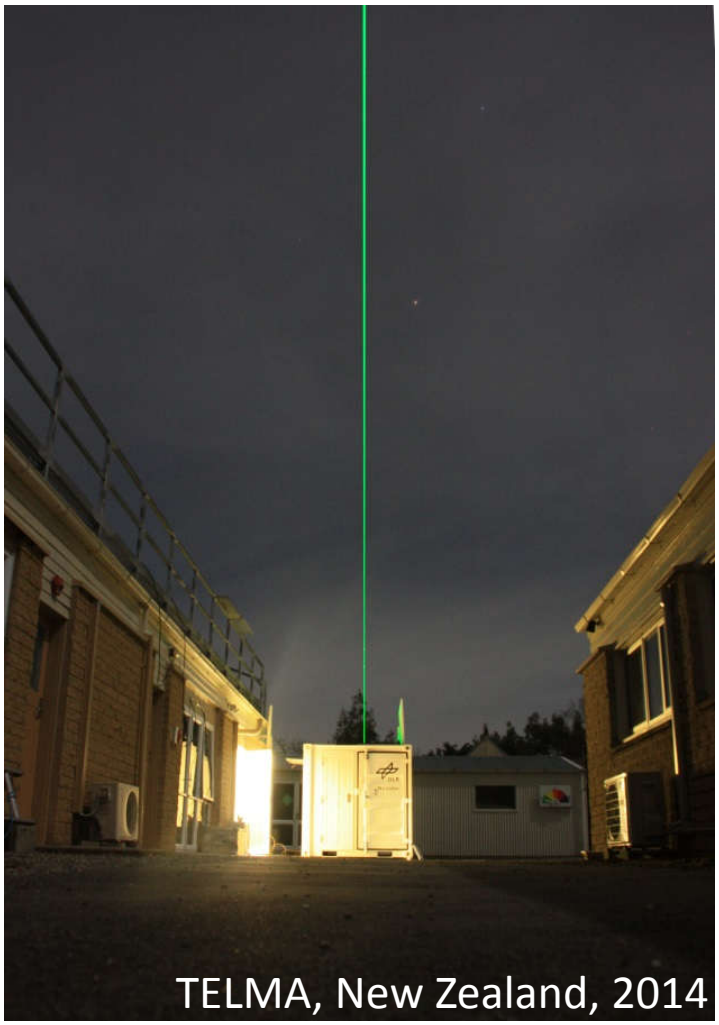


- Temperature perturbation
  = Gravity waves



Vertical filter

Lidar technical description


TELMA, New Zealand, 2014

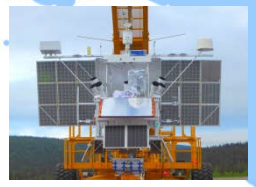
- 14 W laser power, 532 nm, 100 Hz
- 63 cm telescope, 200 µrad FOV
- Multiple Rayleigh and Raman detectors
- Mobile lidar systems (11- and 8-foot container) of 1500 kg
- 2 kW power consumption

DLR

DLR middle atmosphere lidars

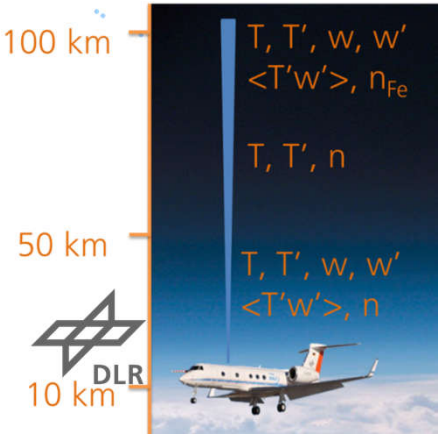
2015/2016: GWCYCLE2

2018: PMC-Turbo
Balloon lidar



2016: ARISE-2

Sep 2019: SouthTRAC
Airborne Lidar

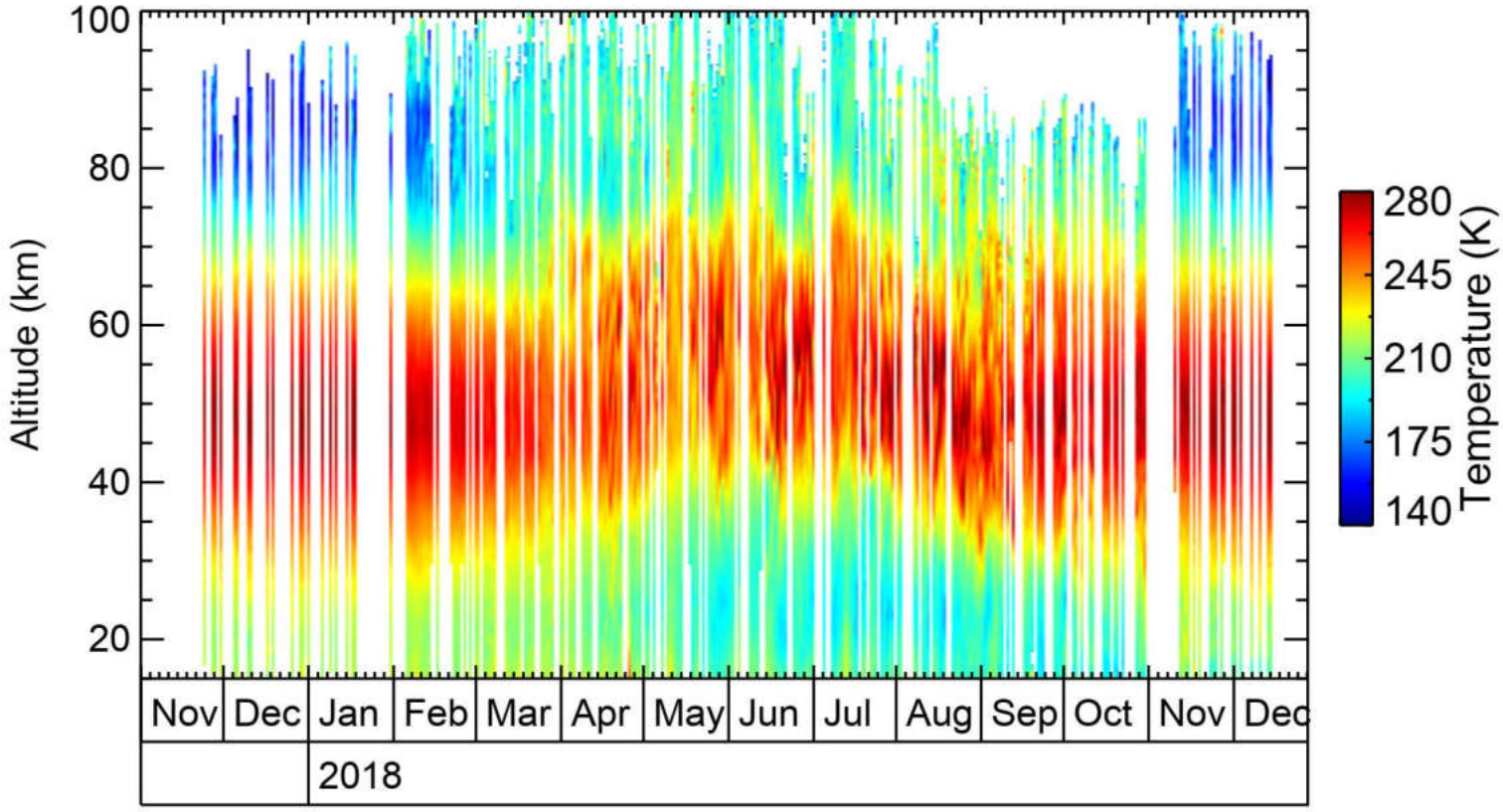


Since 2017: SOUTHWAVE
Fully automatic system

2014: DEEPWAVE

Thermal structure, Rio Grande, 54°S

Laser replacement:
14 W



Summer

Stable stratopause
Cold mesopause

Winter

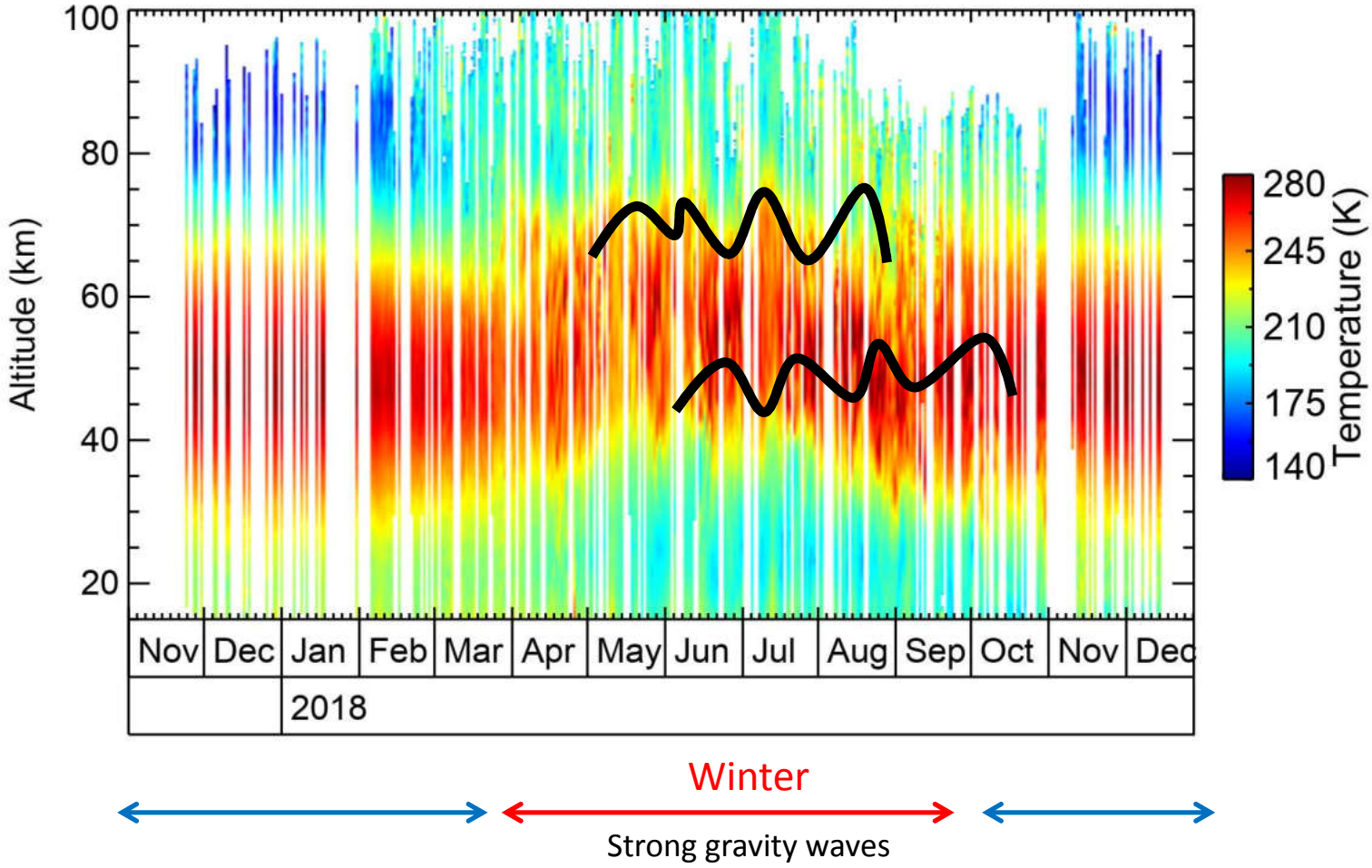
Strong gravity waves

Summer

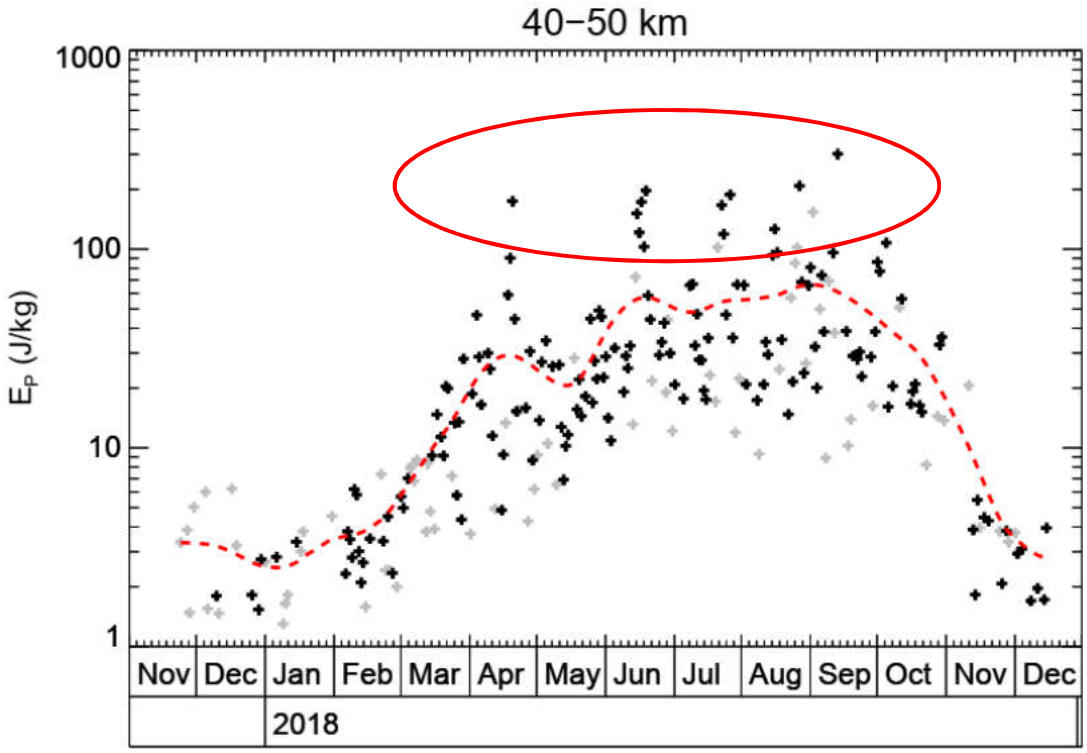
Stable stratopause
Cold mesopause

DLR

3. Gravity waves



Gravity wave activity above Rio Grande, Argentina



- Extreme wave events in winter
- Strongly intermittent

Black symbols: observation period >3 hours; grey symbols <3 hours

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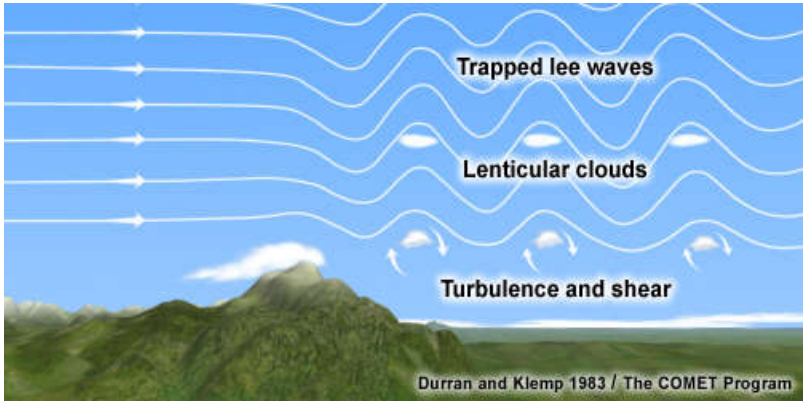
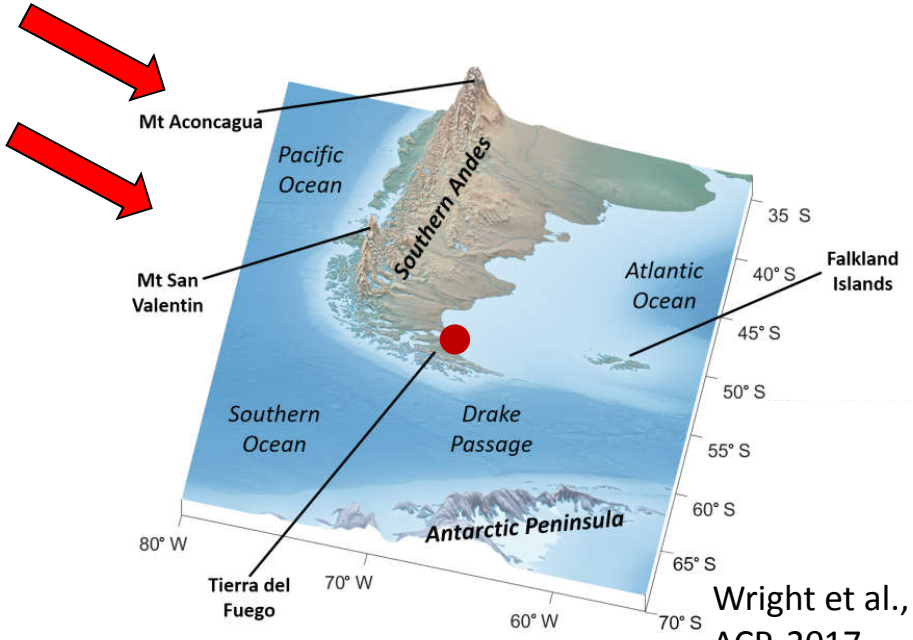
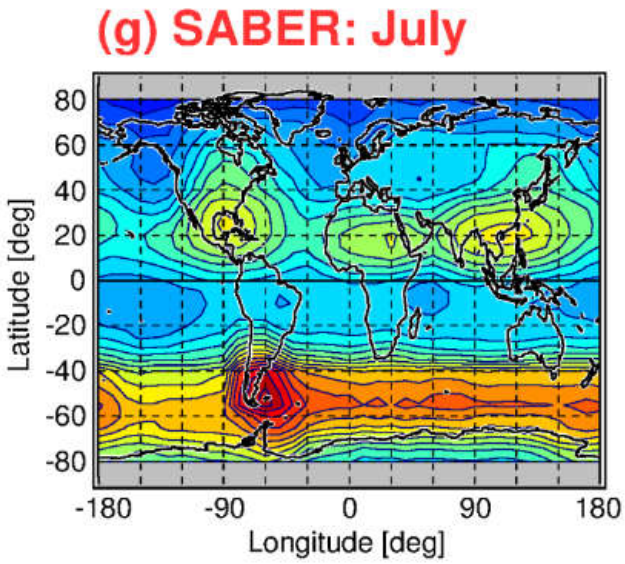
Mountain waves

- You need:
  - Strong winds
  - Perpendicular mountain range





Wright et al., ACP, 2017

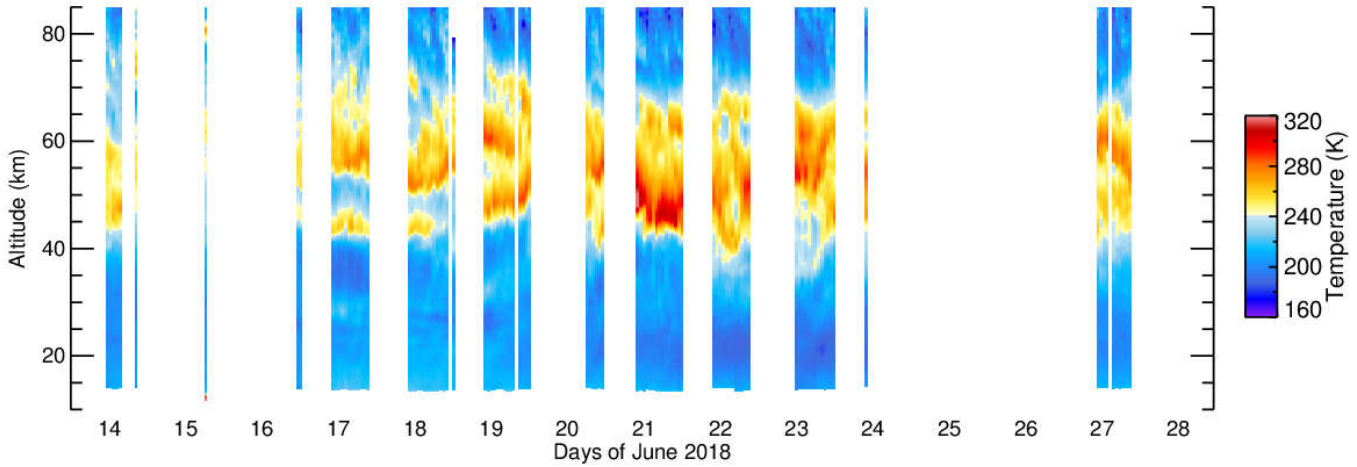


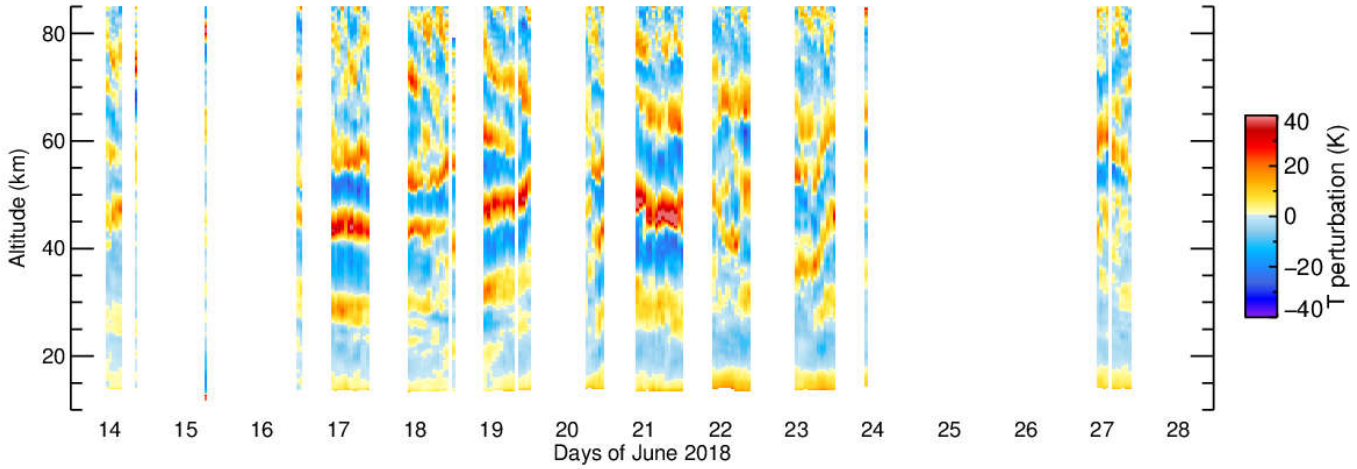
Ern et al., ESSD, 2018

Extreme mountain wave event

- 80 K peak-to-peak amplitude (much more than previous observations)
- Long duration of several days

CORAL lidar observations at Rio Grande



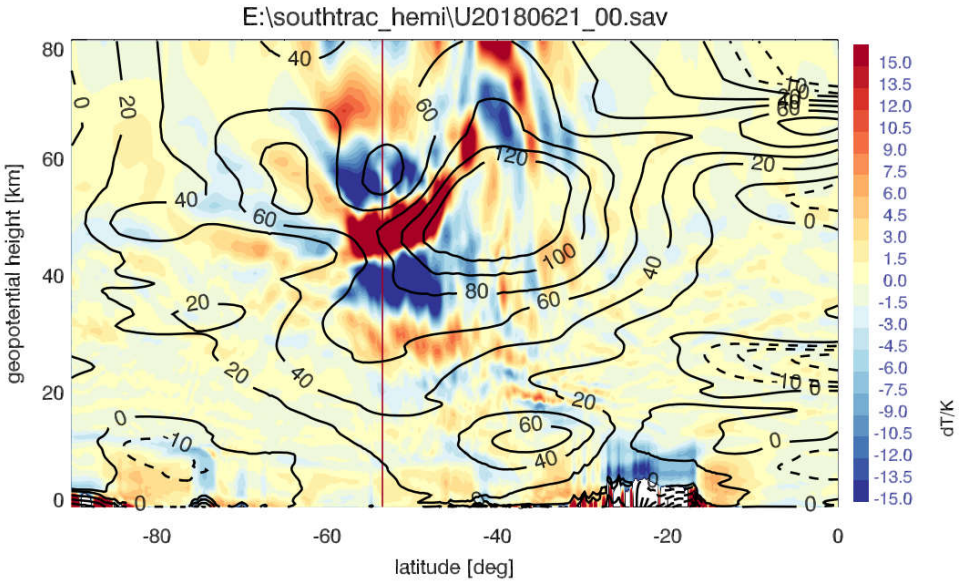


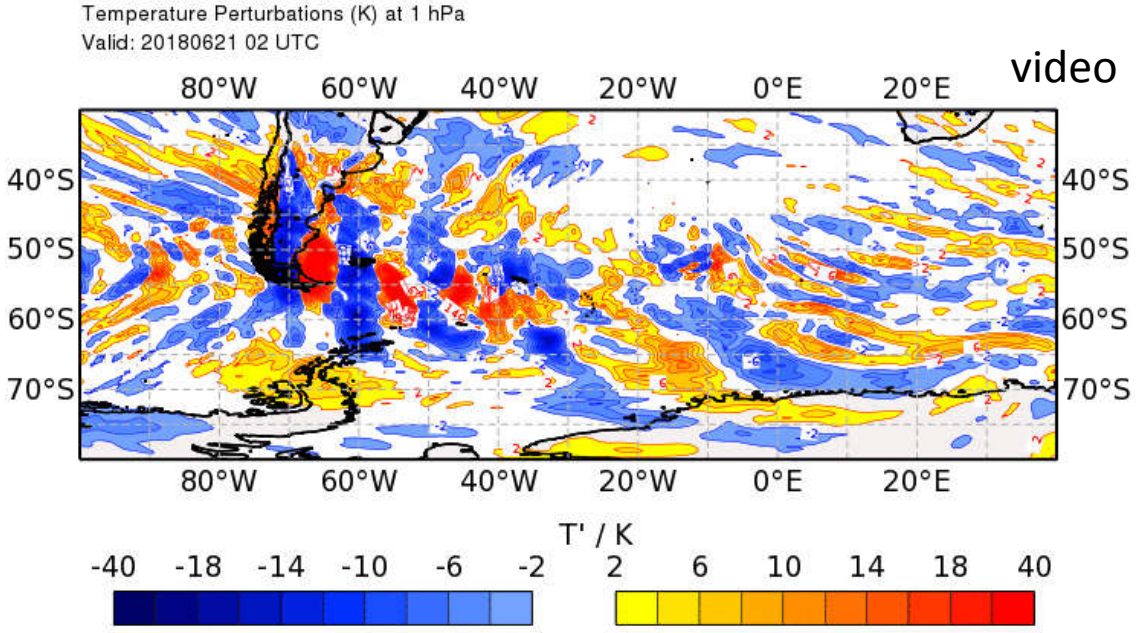
Kaifler et al., in preparation for GRL

DLR

Propagation within the polar vortex edge

- Generation and propagation inside the polar vortex edge
- profound disturbance of stratospheric circulation for several 1000 km





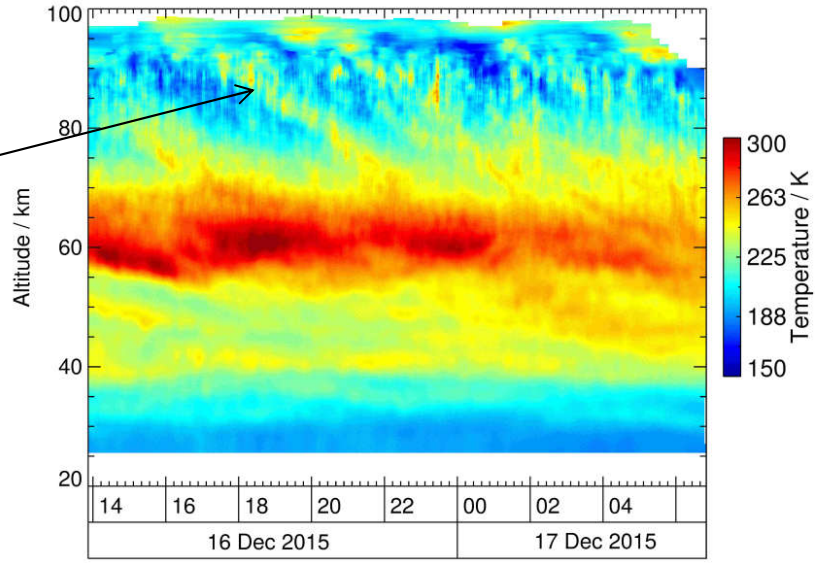
video

Lidar and OH imager

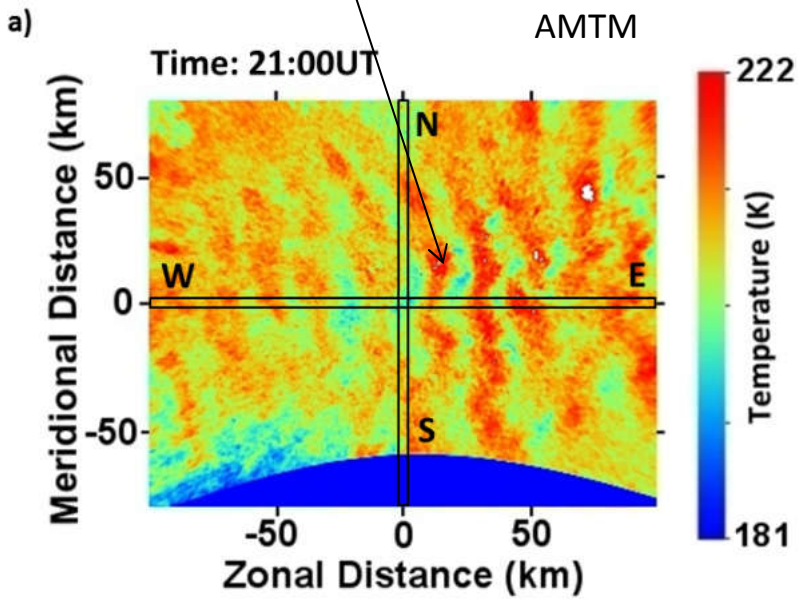
Reichert et al.,
submitted to AMTD

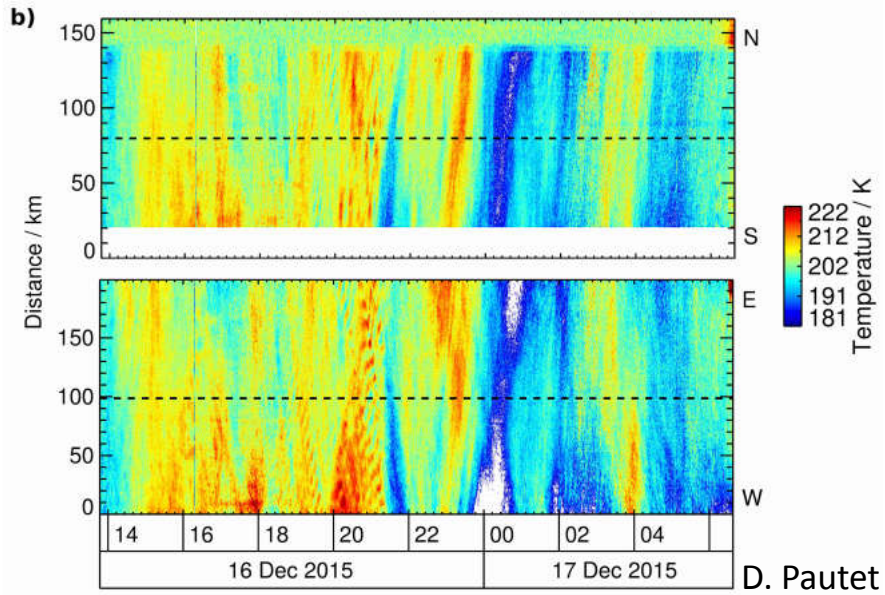
- Strong mesospheric, propagating GW
- GW breaking generating small-scale waves

CORAL lidar



AMTM



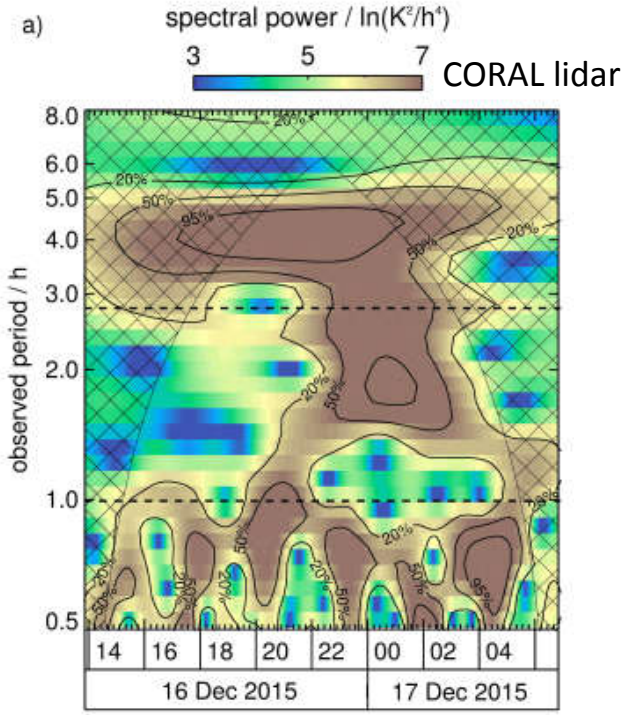


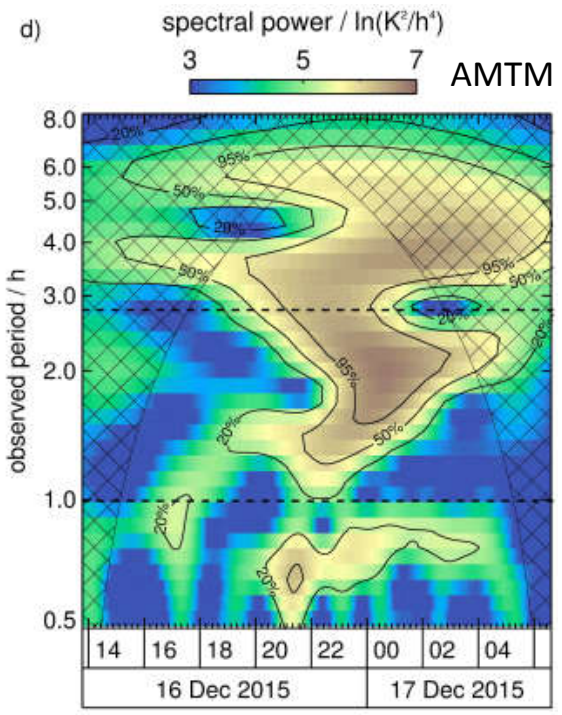
D. Pautet

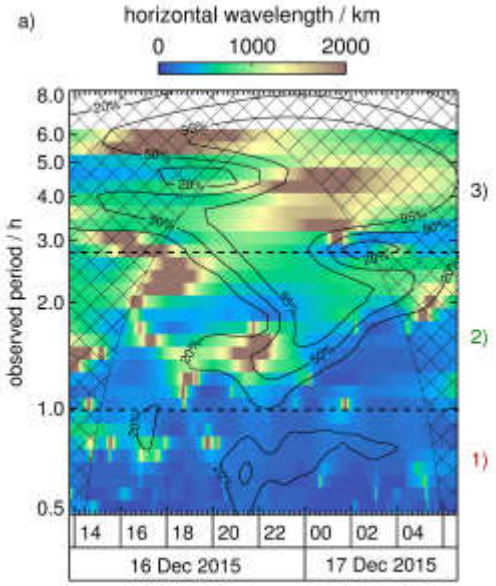
Wavelet analysis

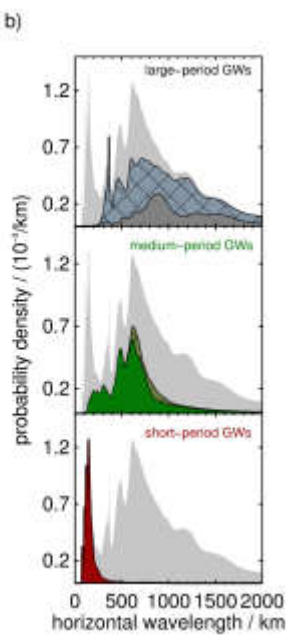
→Gravity wave parameters

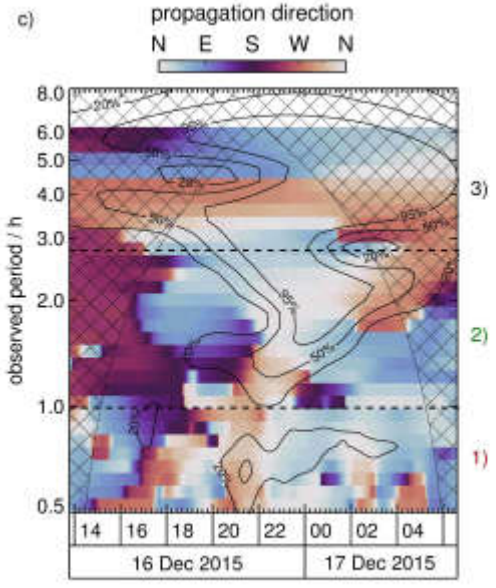
- e.g. 40 min period, 100 km horizontal wavelength, propagating north-west

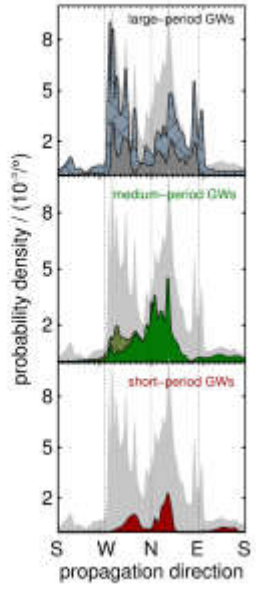






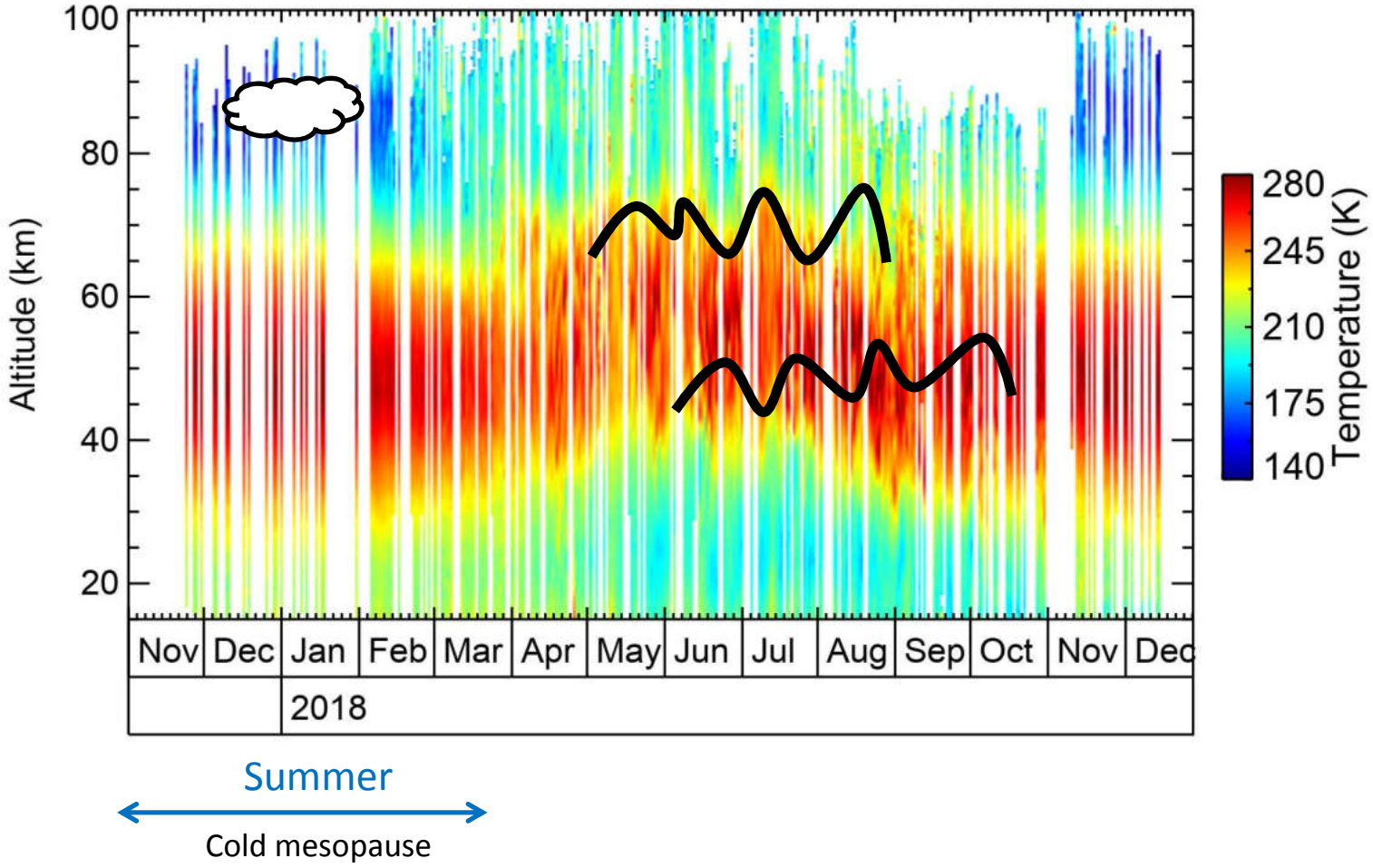




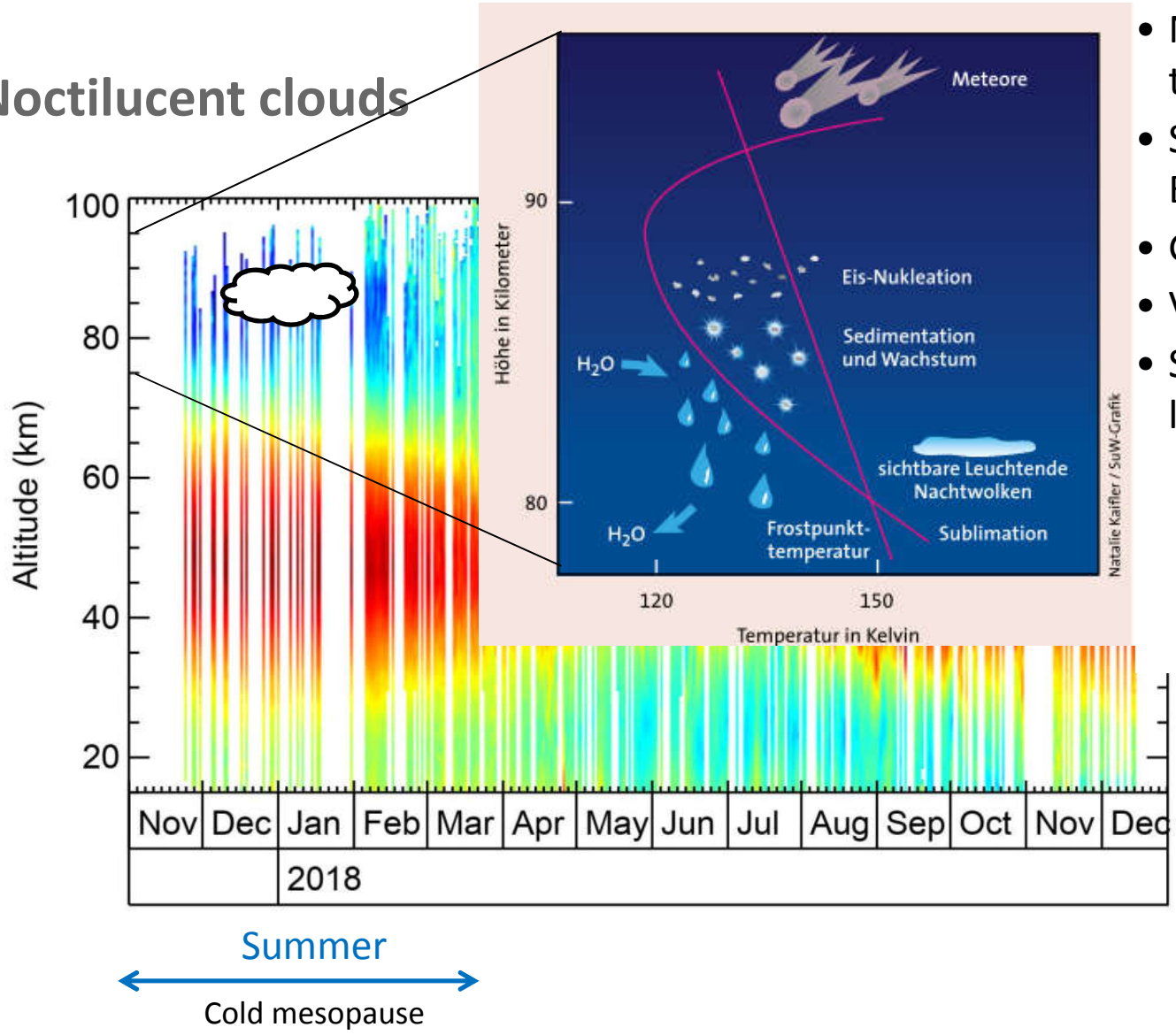


DLR

4. Noctilucent clouds



4. Noctilucent clouds

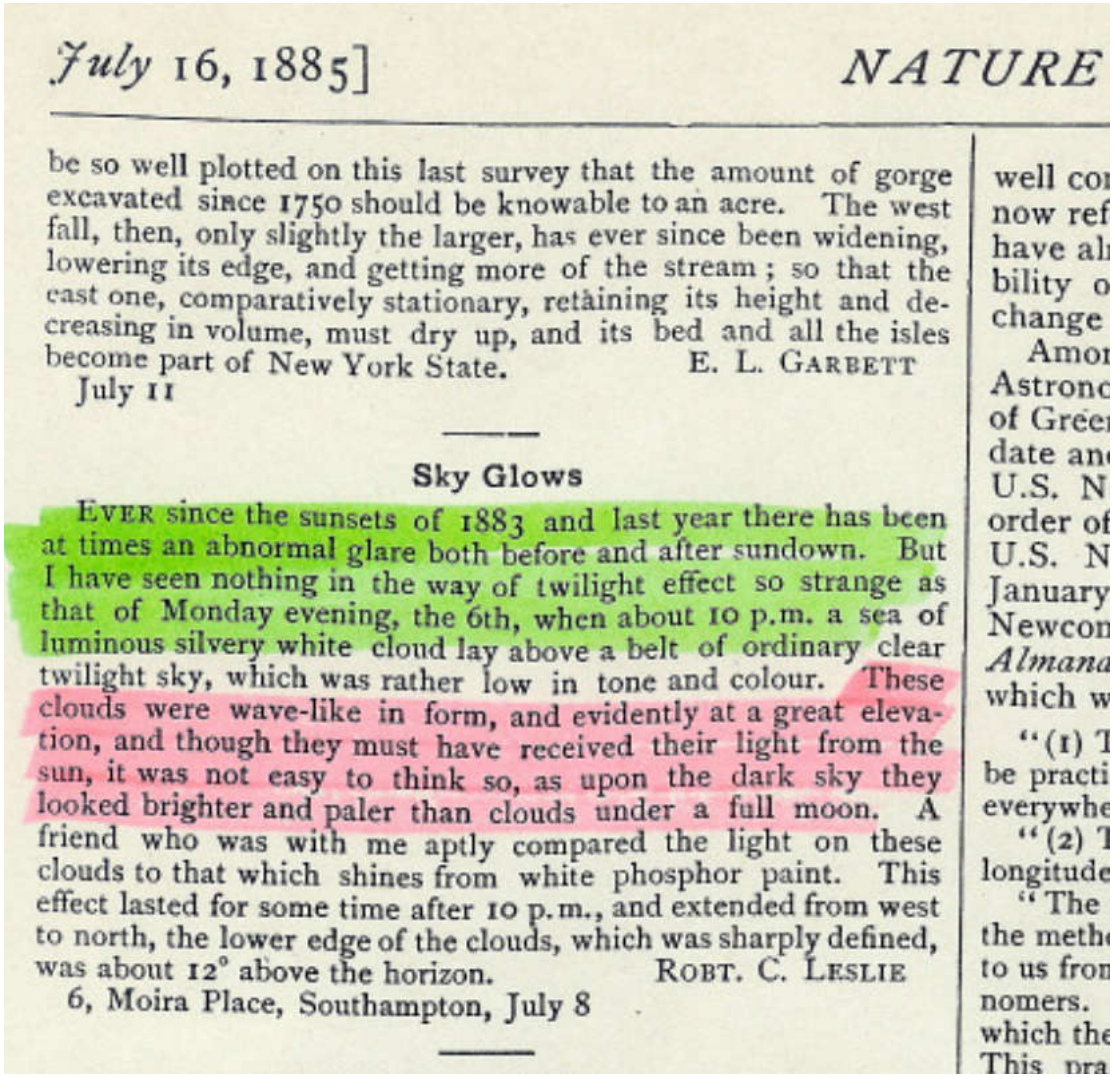


- Nucleation around the mesopause
- Sedimentation in Earth's gravity field
- Growth to ~50 nm
- Visible as NLC
- Sublimation at lower boundary

DLR

History

- Discovery in 1885



July 16, 1885] NATURE

be so well plotted on this last survey that the amount of gorge excavated since 1750 should be knowable to an acre. The west fall, then, only slightly the larger, has ever since been widening, lowering its edge, and getting more of the stream; so that the east one, comparatively stationary, retaining its height and decreasing in volume, must dry up, and its bed and all the isles become part of New York State. E. L. GARBETT

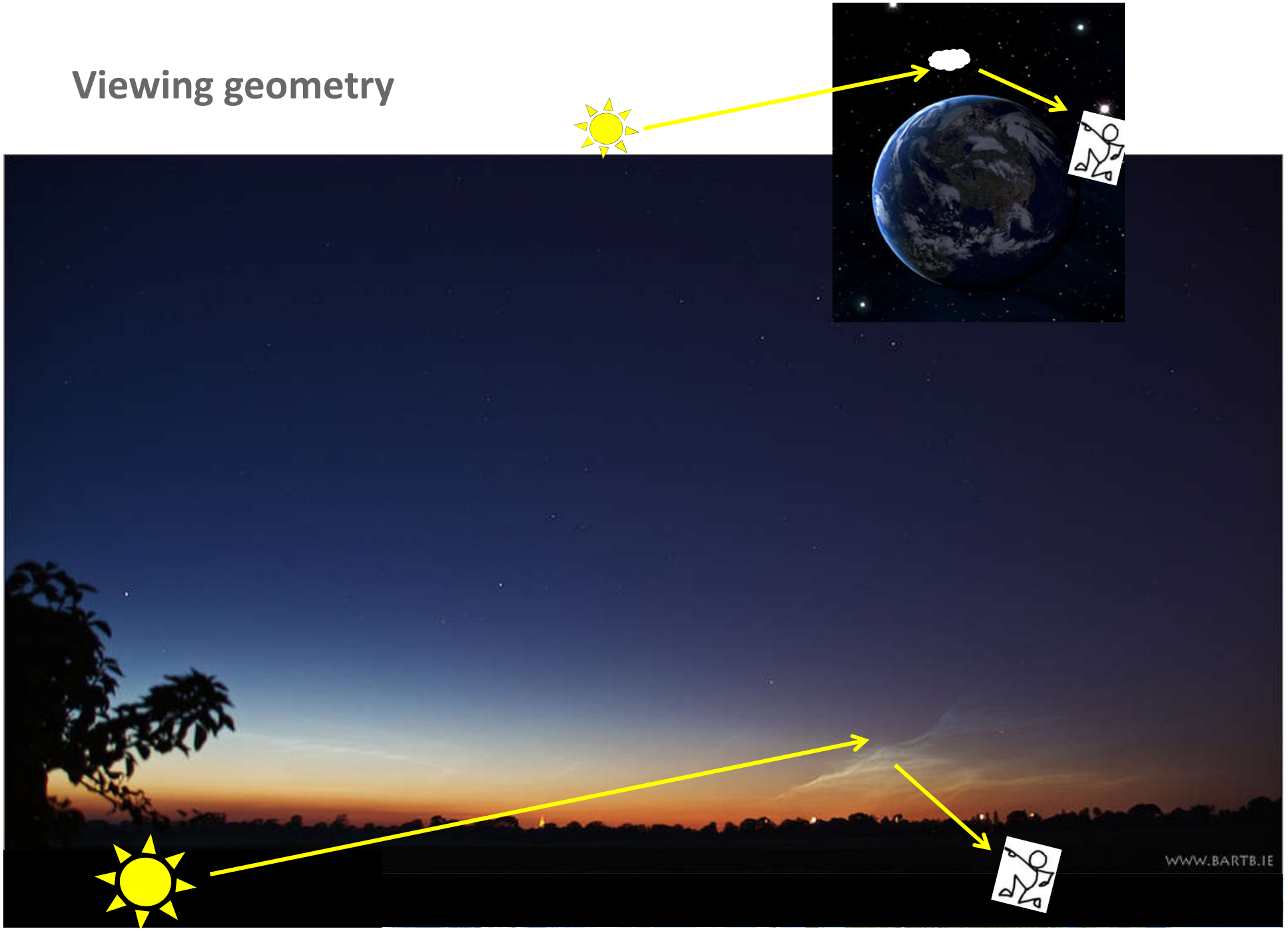
July 11

Sky Glows

EVER since the sunsets of 1883 and last year there has been at times an abnormal glare both before and after sundown. But I have seen nothing in the way of twilight effect so strange as that of Monday evening, the 6th, when about 10 p.m. a sea of luminous silvery white cloud lay above a belt of ordinary clear twilight sky, which was rather low in tone and colour. These clouds were wave-like in form, and evidently at a great elevation, and though they must have received their light from the sun, it was not easy to think so, as upon the dark sky they looked brighter and paler than clouds under a full moon. A friend who was with me aptly compared the light on these clouds to that which shines from white phosphor paint. This effect lasted for some time after 10 p.m., and extended from west to north, the lower edge of the clouds, which was sharply defined, was about 12° above the horizon. ROBT. C. LESLIE

6, Moira Place, Southampton, July 8

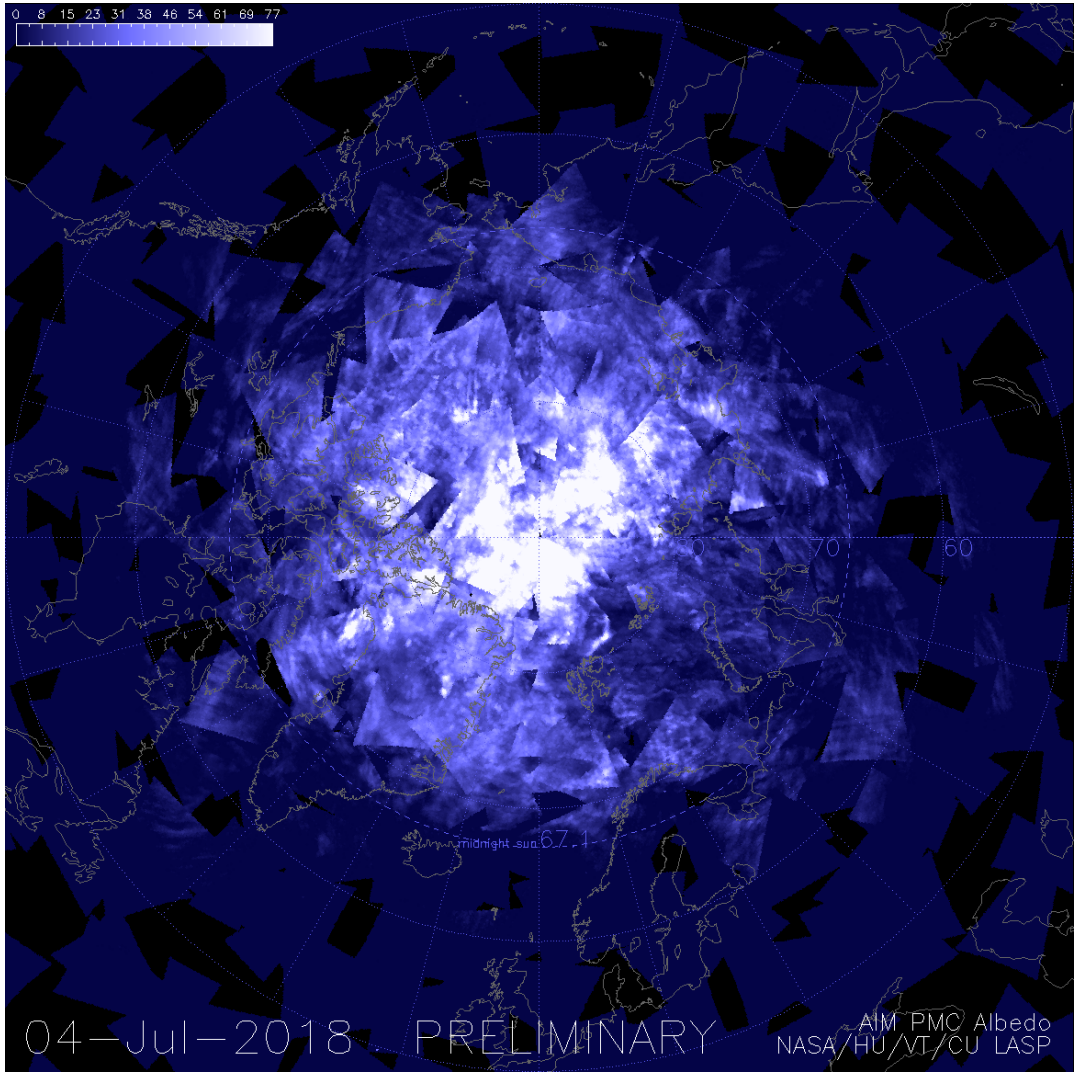
Viewing geometry



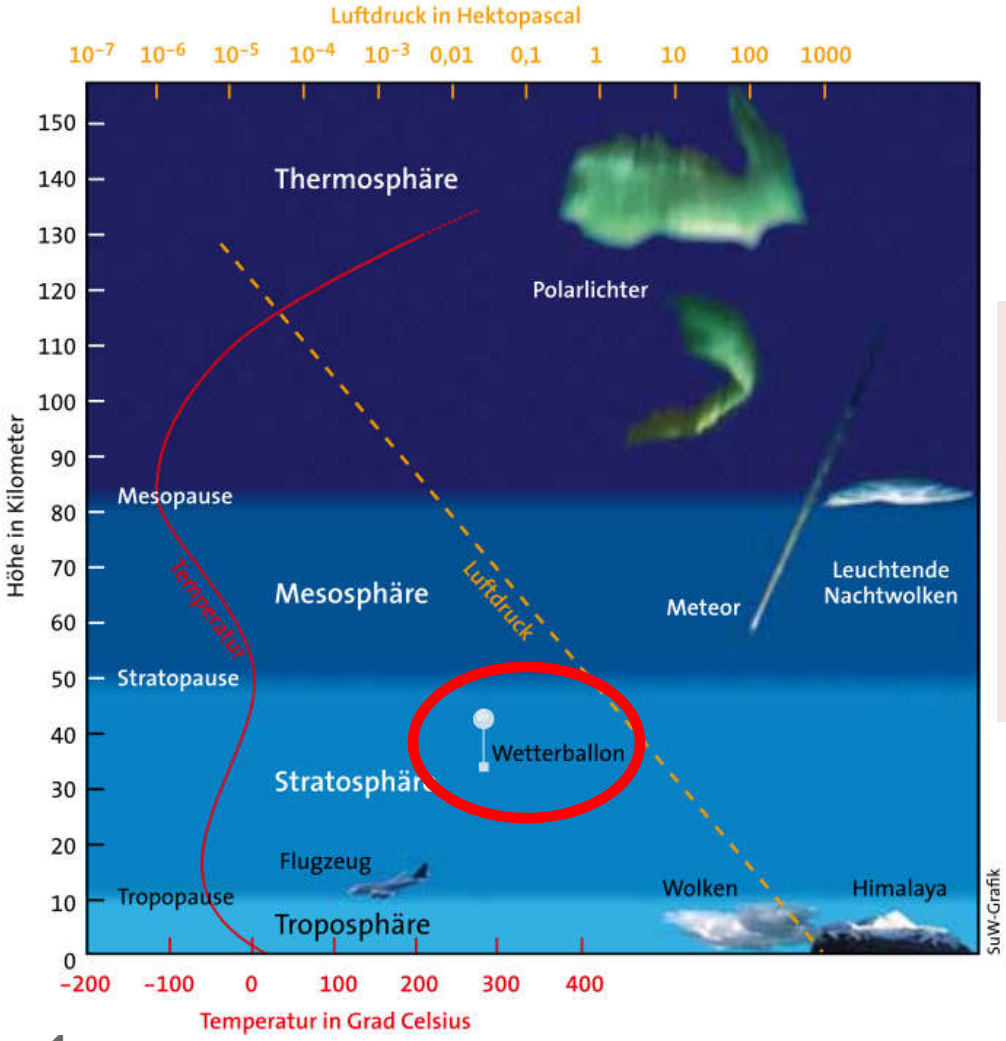
Satellite era

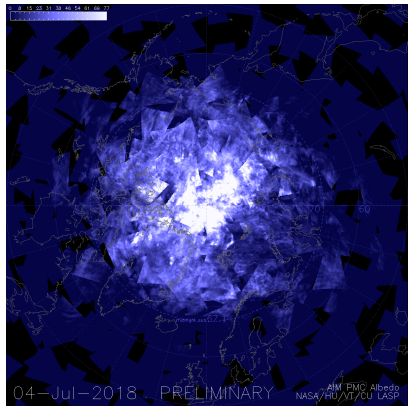
- Nadir-looking high-res CIPS camera on NASA‘s AIM satellite

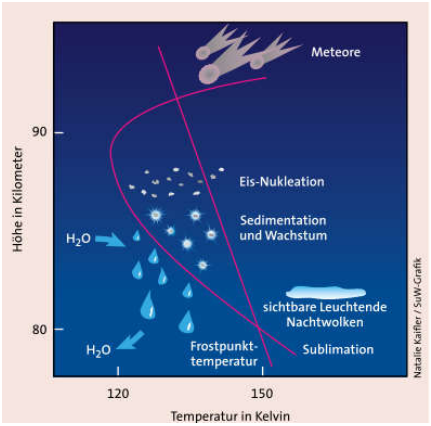
→ small-scale structures: gravity waves



Observation from a balloon platform!

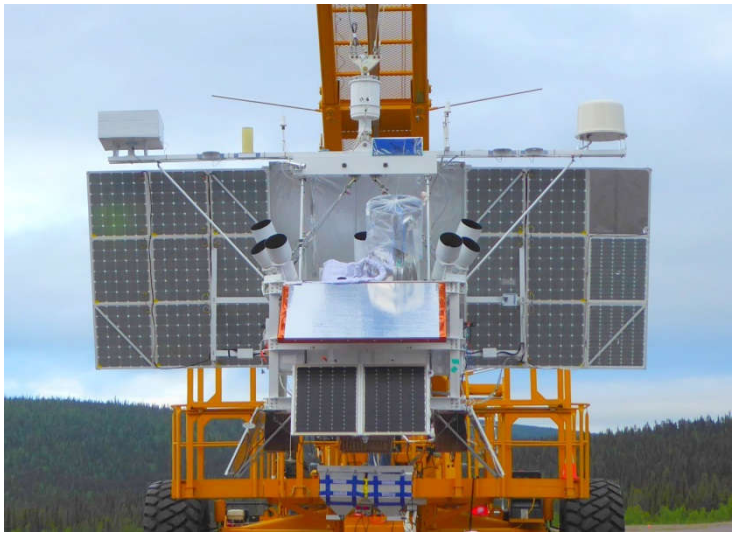






DLR

PMC-Turbo launch from Sweden

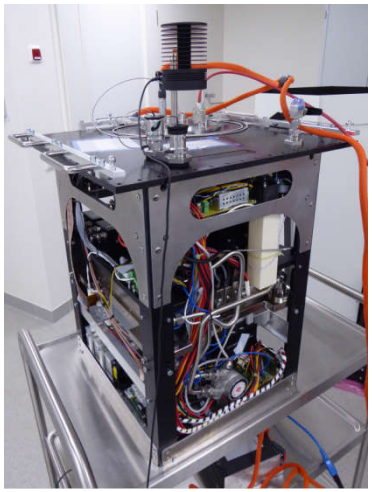


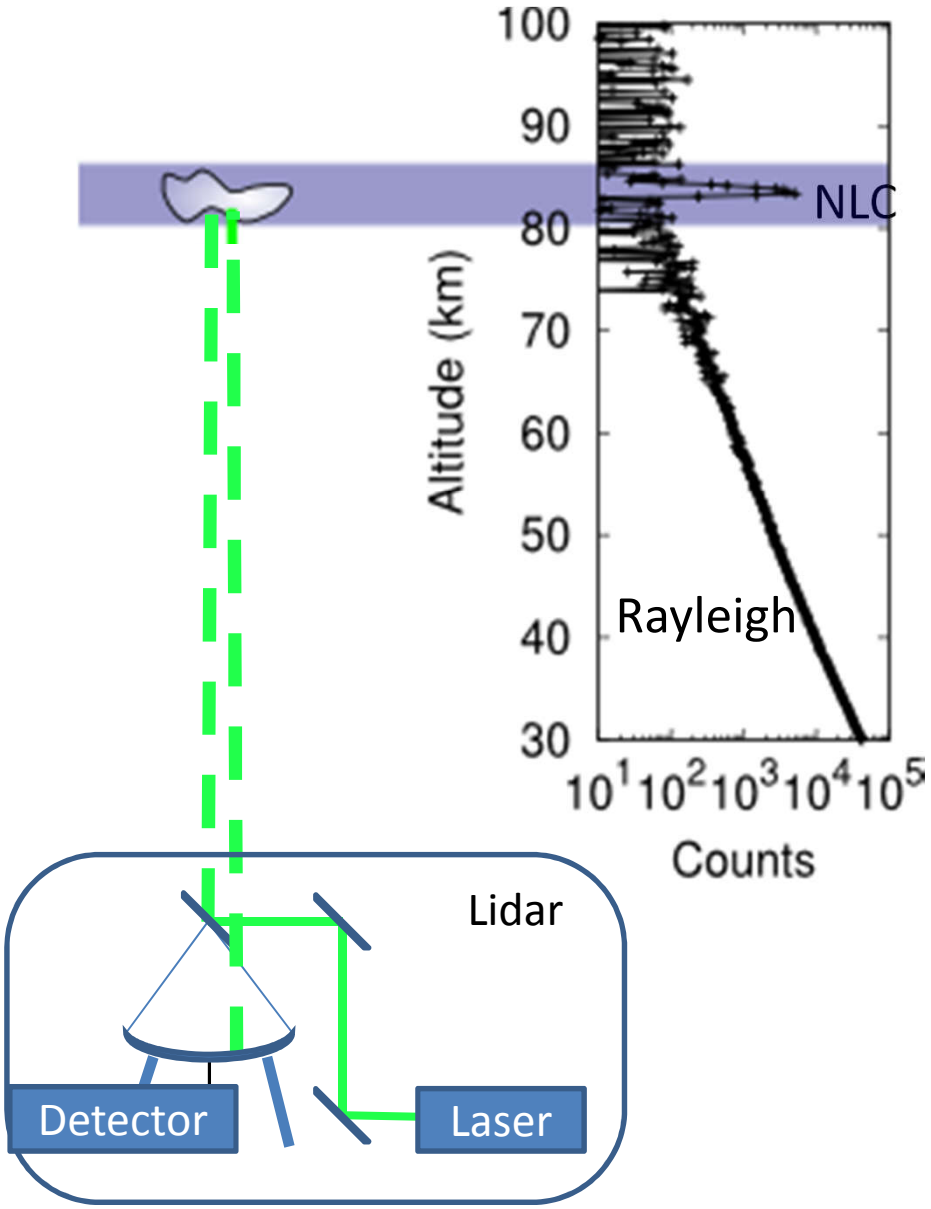
Payload:

Seven cameras and a lidar

NLC observation by lidars

- Laser (5 W, 532 nm, 100 Hz), optics and electronics inside pressure vessel
- 50 cm telescope for receiving backscattered photons





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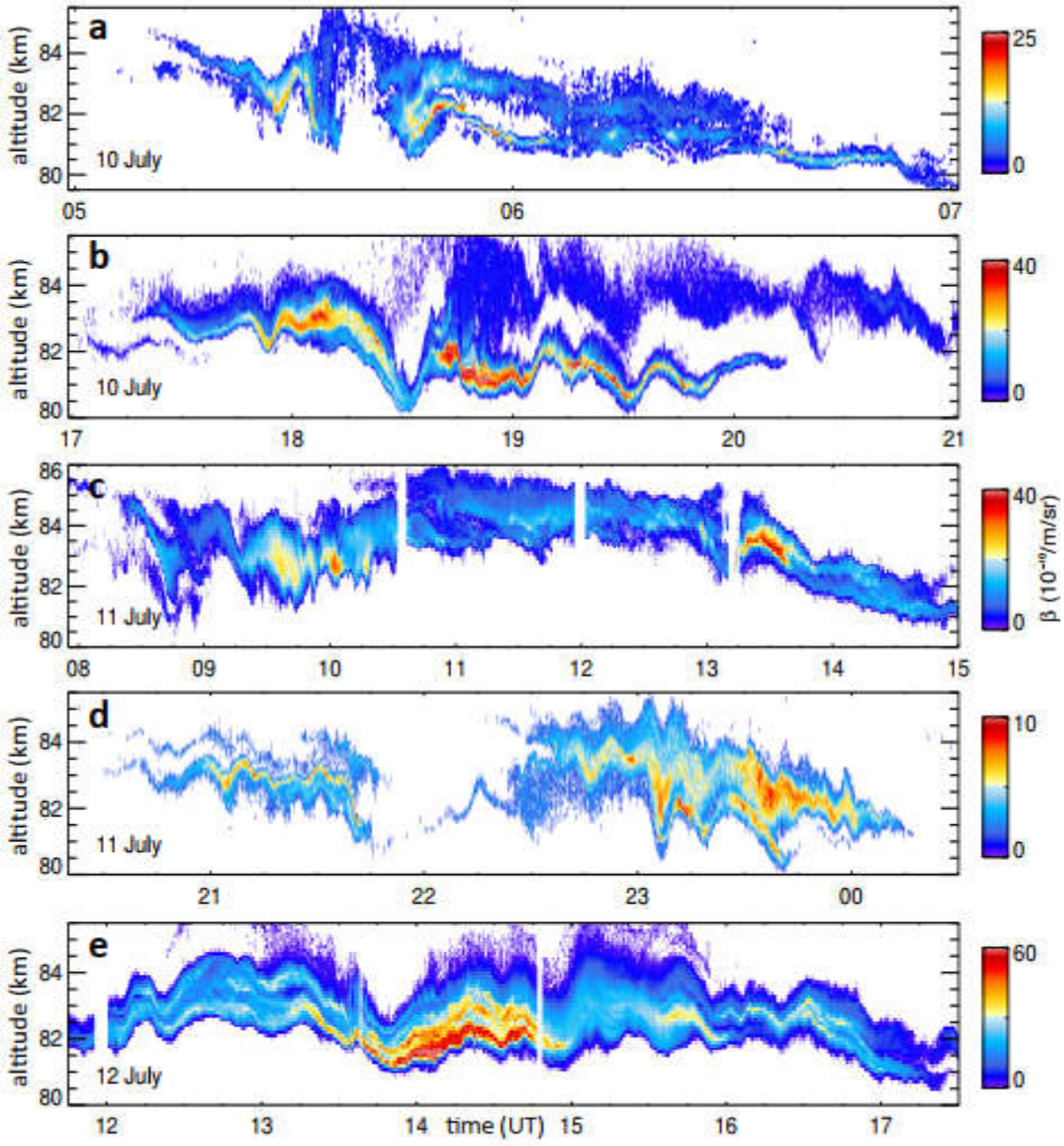
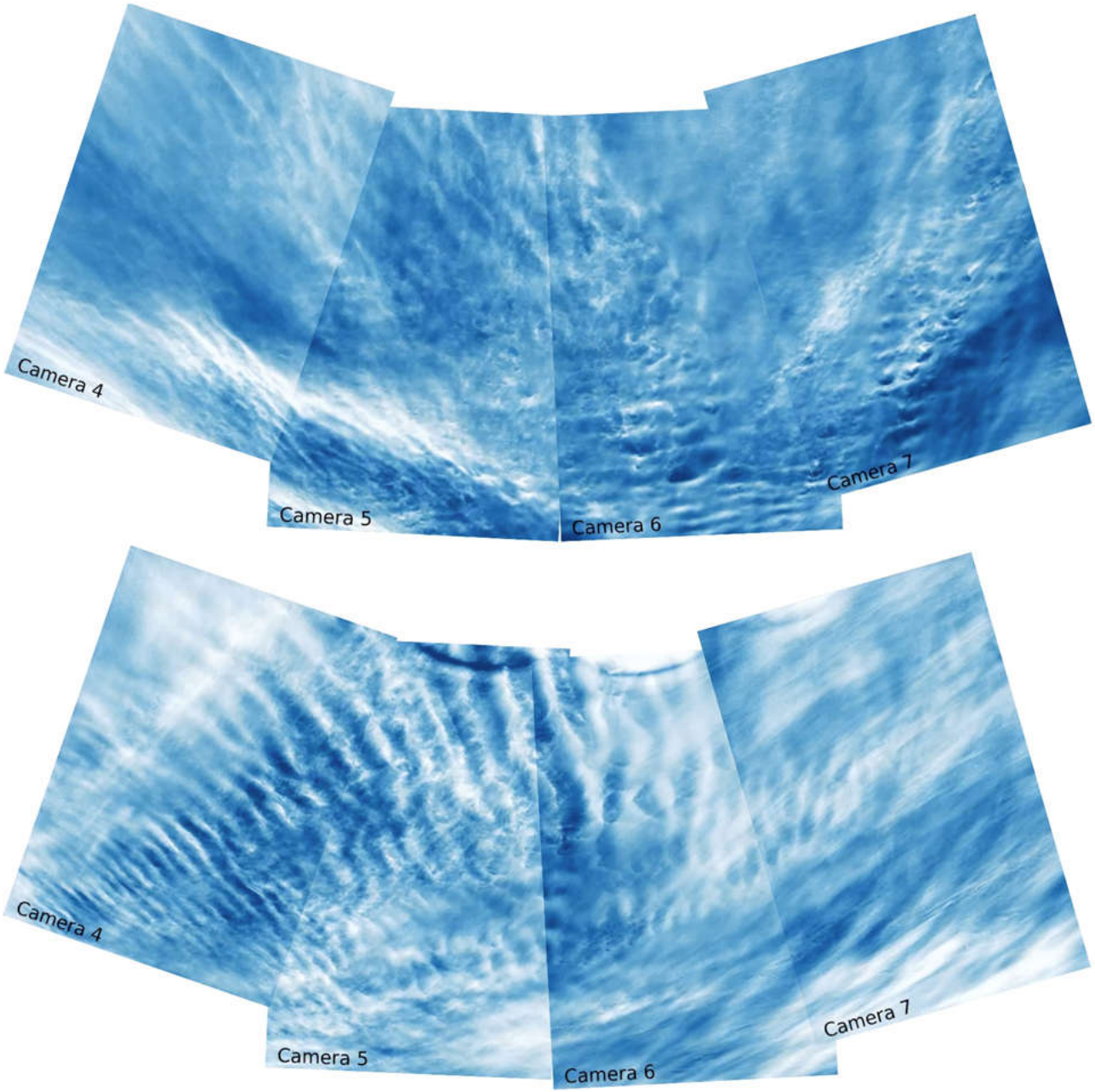
NLC lidar soundings



DLR

Wide-field images



video

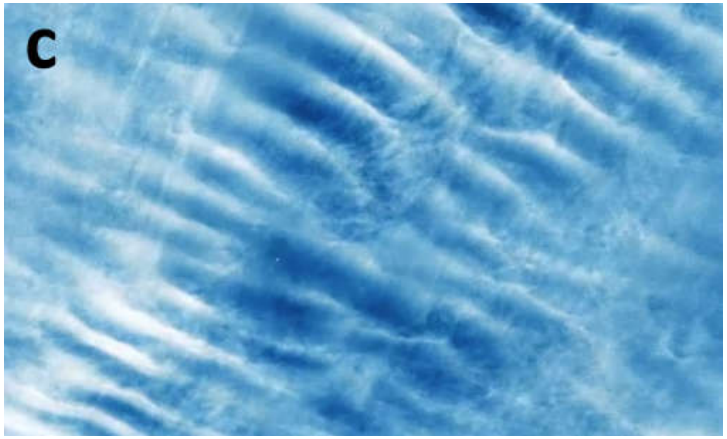
Fritts et al., subm. to JGR

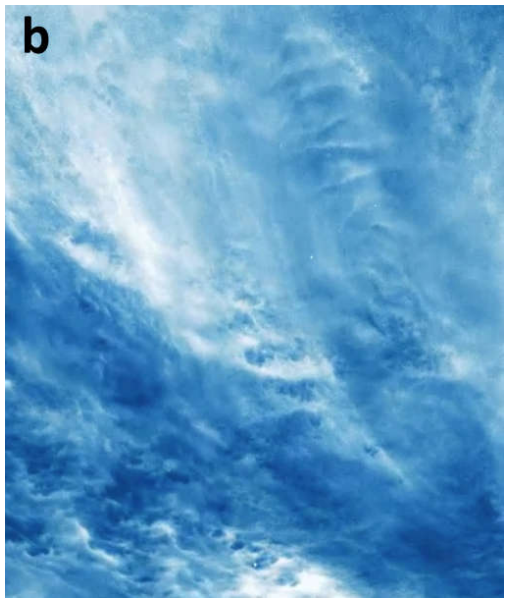
Narrow FOV images

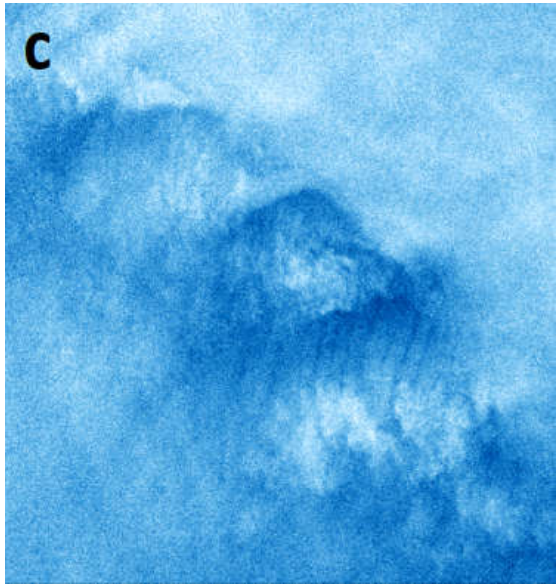
- Turbulence and instability dynamics in high-resolution NLC images:

→ KHI
→ vortices
→ intrusions
→ cusps

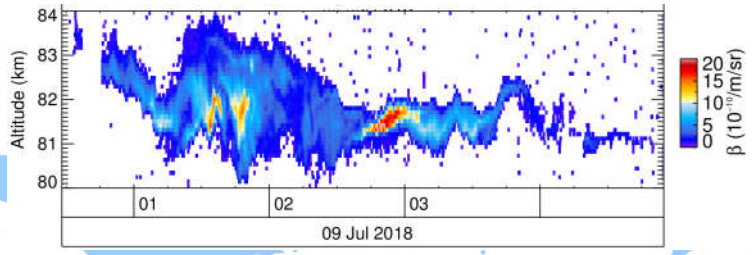
„the best place in the solar system to study turbulence“ – D.C. Fritts

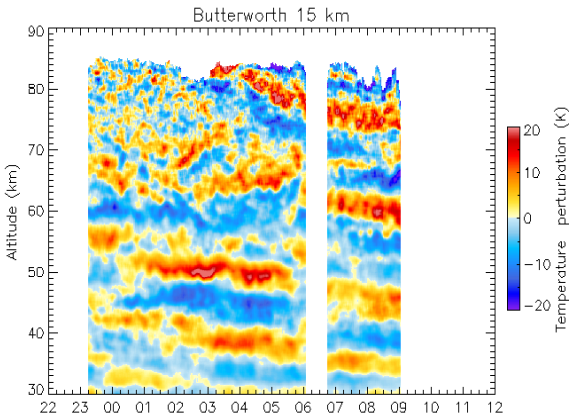




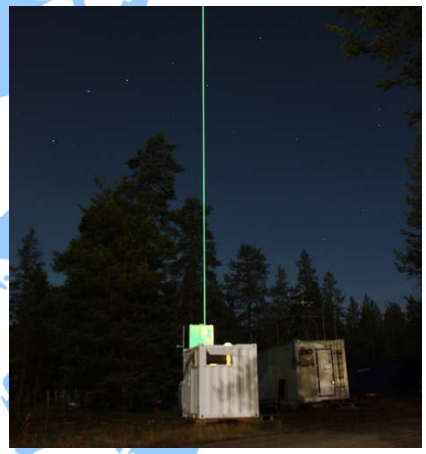


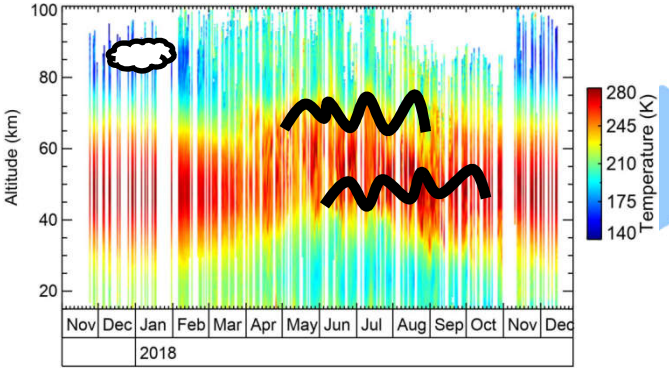
Summary

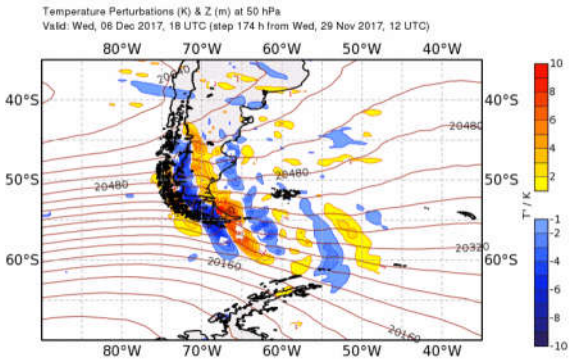




Middle atmosphere dynamics with lidars







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